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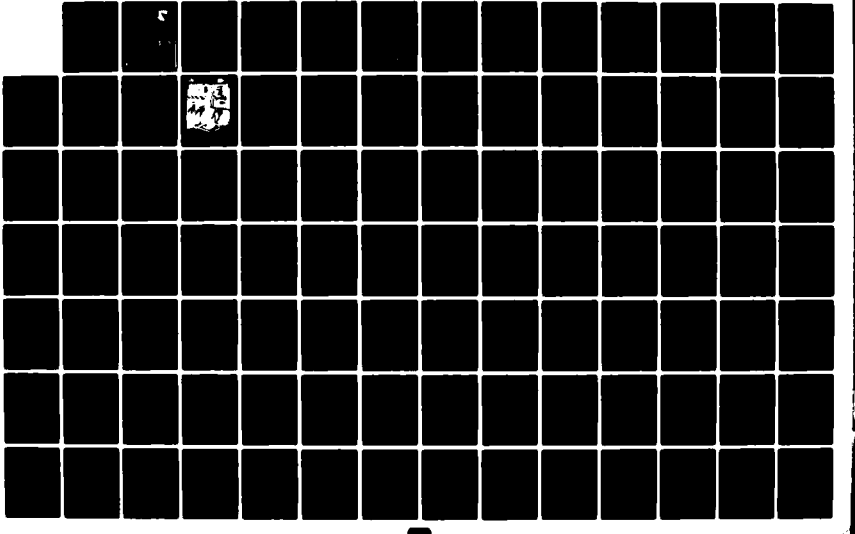

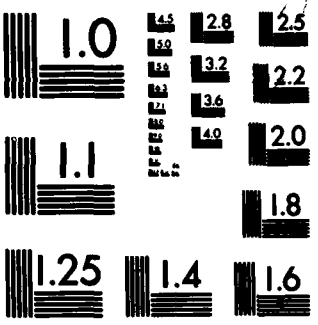

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TOLERANCE LIMITS AND MECHANISMS OF FAILURE OF THE SKELETAL SYSTEM UNDER IMPACT CONDITIONS

G. A. GRAVES
A. A. WOLFF

UNIVERSITY OF DAYTON
300 COLLEGE PARK AVENUE
DAYTON, OHIO 45469

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TECHNICAL REVIEW AND APPROVAL

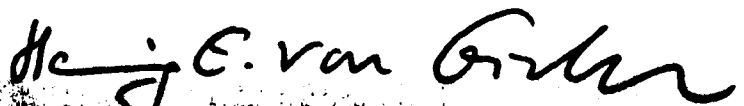
AFAMRL-TR-81-77

The experiments reported herein were conducted according to the "Guide for the Care and Use of Laboratory Animals," Institute of Laboratory Animal Resources, National Research Council.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER



HENNING E. VON GIERKE, Dr Ing
Director
Biodynamics and Bioengineering Division
Air Force Aerospace Medical Research Laboratory

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Bone Histology	Immobilization	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report is a summary of a statistical analysis of data obtained in several related studies on the mechanical, chemical, and histological properties of primate long bones before and after total body immobilization in plaster casts. Statistical correlations and their significance were determined for more than 60 mechanical, chemical, and histological bone parameters. The parameters were evaluated on primates (rhesus) consisting of contro', immobilized, immobilized and exercised, and immobilized and reconditioned groups of animals. A second study on the effect of steroids on the tensile strength of knee ligaments is

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also included in the report. The data obtained were statistically evaluated and the results are presented in this report.

PREFACE

The research covered in this report was performed at the Air Force Aerospace Medical Research Laboratory (AFAMRL), Wright-Patterson Air Force Base, Ohio, under contract F33615-79-C-0502 in collaboration with the Fels Research Institute, Yellow Springs, Ohio, under contract F33615-72-C-1512 and Henry Ford Hospital, Detroit, Michigan, under contract F33615-71-C-1207. This program was conducted in support of workunit 2312-V3-12, "Comparative Response of Man and Animals Exposed to Bioengineering Division, AFAMRL, as principal investigator.

SUMMARY

The major portion of this report is a description and discussion of results of a statistical analysis performed on the data collected in an extensive study of the effects of immobilization on the mechanical, physical, chemical, and histological properties of primate bone. Also included is a brief discussion of a statistical analysis performed on data collected in a study of the effects of steroids on the mechanical properties of primate anterior cruciate ligaments.

The most important portion of the immobilization data represents the results of in-vitro failure tests of long bones during mechanical loading. (The bones were taken from groups of control animals, totally immobilized animals, immobilized animals with one leg exercised, and totally immobilized animals that were allowed to "recondition" for periods of five and 12 months.) The mechanical property results were obtained from bones subjected to torsional loading to failure under high-strain rate conditions. Mechanical parameters were obtained directly from oscillographic recordings. The mechanical parameters included the maximum linear load, maximum load, rotation to maximum linear load, rotation to failure, energy to maximum linear load, and energy to failure.

The Fels Research Institute (FRI), Yellow Springs, Ohio, determined bone volume, dry and ash weight, and calcium, phosphorus and magnesium concentrations. These quantities were measured not only for the mechanically tested bones, but also for selected additional bones taken from the same animals. The Henry Ford Hospital (HFH), Detroit, Michiga', analyzed bone cross-section specimens from the tibia, femur, and fibula to determine their histological bone dynamics. Tetracycline labeling and quantitative microscopic techniques were used in these histological analyses. The physical and chemical property data and histological data were then used to determine if statistically significant correlations existed between these parameters and mechanical strength properties.

The long-range objective of the immobilization study was not only to describe the strength and failure dynamics of long bones, but also to discover and describe the biological mechanisms governing the behavior of the biomechanical, physical, chemical, and histological parameters of bone remodeling which affect bone strength. These objectives were to be accomplished by developing statistical methods for reducing a vast amount of data and thereby determining the significant correlations existing between these parameters. This information will aid in explaining clinically observed in-vivo fracture behavior believed to be a result of immobilization. The steroid study was designed to provide information which would aid in the judicious clinical use of steroids.

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LIST OF SYMBOLS AND ABBREVIATIONS
(Listed in approximate order used)

* - significant at the 0.05 level

** - significant at the 0.01 level

*** - significant at the 0.005 level

C - "control" group of monkeys; not immobilized

I - "immobilized" group of monkeys; immobilized in total body cast

ER - "exercised right" group of monkeys; casted, but with right leg attached to exercise apparatus

EL - "exercised left" group of monkeys; casted, but with left leg attached to exercise apparatus

E - used to refer collectively to both ER and EL groups. Also used when a study employed only one "exercised" group of monkeys; i.e., when all the monkeys in that study's "exercised" group had the same (usually the right) leg attached to the exercise apparatus.

R_5 - group of monkeys reconditioned in the gang cages for five months after immobilization

R_{12} - group of monkeys reconditioned in the gang cages for 12 months after immobilization

R - used to refer collectively to both R_5 and R_{12} groups

MLL - maximum linear load ($cm \cdot kg_f$)

ML - maximum load

RMLL - rotation to maximum linear load (degrees)

RFL - rotation to failure (degrees)

EMLL - energy to maximum linear load ($cm \cdot kg_f$)

EFL - energy to failure ($cm \cdot kg_f$)

VOL (or Vol) - volume (mm^3)

Dry Wt (or DrWt) - dry weight (mg)

Ash Wt (or AWt) - ash weight (mg)

Dens - density; the ratio of dry weight to volume (mg/mm^3)

Ash Con (or A Con) - ash content; the ratio of ash weight to volume (mg/mm^3)

% Ash (or % A) - percent ash; the ratio of ash weight to dry weight x 100

Ca/DrWt - the ratio of calcium weight to dry weight (mg/g)

Ca/Vol - the ratio of calcium weight to volume (mg/cm^3)

LIST OF SYMBOLS AND ABBREVIATIONS (Concluded)

P/DrWt - the ratio of phosphorus weight to dry weight (mg/g)

P/Vol - the ratio of phosphorus weight to volume (mg/cm^3)

Mg/DrWt - the ratio of magnesium weight to dry weight (mg/g)

Mg/Vol - the ratio of magnesium weight to volume (mg/cm^3)

Ca/P - the ratio of calcium weight to phosphorus weight

Ca/Mg - the ratio of calcium weight to magnesium weight

Ac - cortical area (mm^2)

C/T - the ratio of cortical area to total area

Af - the number of osteoid seams per unit area (mm^{-2})

Ar - the number of resorption spaces per unit area (mm^{-2})

Sf - circumference of osteoid seams (mm)

M - appositional rate (μ/day)

Mf - radial closure rate (mm/year)

μf - activation frequency; the number of foci per unit time ($year^{-1}$)

σf - osteon formation time (years)

Ar/Af - the ratio of resorption to formation

Vf - bone formation rate (mm^2/mm^2/year)

W.O.S. - width of osteoid seams (μ)

% - percent labeled system

W.T. - wall thickness of completed osteon (mm)

P - perimeter (mm)

surface Vf - surface-based bone formation rate (mm^2/mm^2/year)

M.C.T. - mean cortical thickness (mm)

volume Vf - volume-based bone formation rate (mm^2/mm^2/year)

SECTION 1

IMMOBILIZATION STUDY PROCEDURE

1.1 SUMMARY

Young adult male rhesus monkeys were divided into four main groups in order to study the effects of immobilization on various mechanical, physical, chemical, and histological parameters of primate bone. The groups included an untreated control group; an immobilized group, in which each subject was placed in a total body cast; an exercised group, in which each subject was placed in a total body cast with one leg allowed to remain free; and a reconditioned group, in which each subject was totally immobilized in a body cast and then allowed to recondition in a large gang cage. After the completion of the experimental period, certain bones were removed from each animal and subjected to mechanical testing. These bones, as well as selected additional bones, were then analyzed for various physical, chemical, and histological parameters.

1.2 ANIMAL AND SPECIMEN TREATMENT

The bone specimens were obtained from male rhesus monkeys located at AFAMRL, Veterinary Division, at Wright-Patterson Air Force Base, Dayton, Ohio. All animals had been captured in their wild state. The animals were all of a late adolescent age with closing long bone epiphyses. They were maintained in cages measuring 3 ft. x 3 ft. x 4 ft. The animals were examined frequently and were demonstrated to be disease-free prior to the initiation of the study. Throughout the experiment, they were fed commercial monkey chow and water in optimum amounts based on weight. All monkeys were injected with 25 mg/kg intramuscular tetracycline at certain intervals in order to label their bones for later histological analysis.

The monkeys in the control group were placed in a large gang cage (6 ft. x 8 ft. x 10 ft.) with female mates to simulate as nearly as possible their normal native activity. The animals were extremely active in the larger cages.

The monkeys in the immobilized group were immobilized in plaster. The plaster casts, as shown in Figure 1, extended to the neck. Careful attention to many factors, including positioning, hand-feeding, proper nutrition, and fluid intake was given by personnel at the AFAMRL veterinary facility.

Each monkey in an exercised group was similarly immobilized, but one leg, either right or left, was freely movable and the free foot was strapped to a foot pedal which, when pushed down about 12 inches, released a banana pellet into the monkey's mouth. The force needed to push the pedal from the resting to

Figure 1. Monkeys Immobilized in Plaster Casts.

the lower position could be adjusted by changing the weights pulling the pedal over a pulley wheel. An average of five pounds was used, resulting in five-foot pounds of work per pedal depression.

After completion of the experimental period, the animals in the control, immobilized, and exercised groups were sacrificed by phenobarbital overdose and the bone specimens were prepared. The monkeys in the reconditioned group, which until this time had received treatment identical to those in the immobilized group, were not killed but were returned to the gang cage for a reconditioning period of either five or 12 months. At the end of the reconditioning period, these animals were sacrificed by phenobarbital overdose and the bone specimens were prepared. All bones used in this study were stored frozen at -15°C for long term storage and refrigerated at 4°C for storage periods of less than 24 hours. Bones in this study were typically frozen (long term) for less than six weeks.

The tibiae, femora, and humeri were dissected free of surrounding tissues, leaving the surface membrane (periosteum) intact to insure that no surface scratches were inflicted. Storage and testing time, temperature, and humidity conditions were controlled at all times. Specimens for all tests were stored in individually labeled plastic bags containing Ringer's solution, to maintain the proper moisture content of each specimen.

A standard procedure was followed during the bone torsion tests: (1) The specimen was removed from the plastic bag of Ringer's solution and taken to the test apparatus. During a period of less than one minute, each long bone specimen was protected from drying by covering with a towel soaked in Ringer's solution. This protection was allowed to remain until immediately before the start of the test (less than ten seconds in every case). (2) The specimen was tested to failure at a rapid loading rate. (3) After testing, the specimen was returned to the labeled plastic bag and stored at a low temperature for later analysis.

Small whole bones, such as calcanei, tali, metatarsals, and vertebrae were placed in small jars and frozen immediately after necropsy. The soft tissue was removed from these bones by placing them in large glass jars with colonies of dermestid beetles. These colonies were kept under appropriate environmental conditions. After this treatment the bones were extracted in chloroform-methanol (2:1) for complete removal of fat and then stored dry.

All samples from the ulna were cleaned by hand.

1.3 DATA COLLECTION

All of the data used in the analyses were provided by AFAMRL personnel as acquired from the various laboratories. The mechanical property data (i.e., both long bone torsion data and ligament strength data) were submitted in the form of load-deformation curves that required an additional step to reduce the data to digitized form. The physical property data (usually referred to as "ash data"), chemical data, and histological data were submitted in tabular form.

As the data were acquired, they were compiled in nine separate groups. Each group (listed below) was put into a separate log.

I. DATA BOOKS

A. Immobilization Study

1. Fractured Bone Data - Torsion, Ash, and Chemical data for TIBIA, FEMUR, HUMERUS
2. Whole Bone Data - Ash and Chemical data for TIBIA, FEMUR, HUMERUS, RADIUS, FIBULA, ULNA
3. Small Bone Data - Ash and Chemical data for TALUS, CALCANEUS, ULNA, METATARSALS 1, 2, 3, and 4
4. Vertebral Body Data - Ash and Chemical data for Bodies (D12, L2) and Cores (D11, L1, L7)
5. Tibia Histology Data - Haversian, Endosteal, and Periosteal data
6. Femur Histology Data - Haversian, Endosteal, and Periosteal data
7. Fibula Histology Data - Haversian, Endosteal, and Periosteal data.

B. Steroid Study

1. Ligament Strength Data - groups 3-13
2. Slope Data - groups 1-13

II. TABLES OF MEANS, STANDARD DEVIATIONS, AND RANGE TEST RESULTS

A. After the data collection for the immobilization study was complete, tables (see Appendix D) of means and standard deviations were generated by the program MEANDIF. Using the data generated

in the MEANDIF program, analyses of variance and range tests were completed and the results were included in each of the 54 tables generated for the mean and standard deviation (see IMMOBILIZATION STUDY, PROCEDURE, DATA TREATMENT, Analysis of Variance and Range Test).

B. The results of the analyses of variance and range tests were tabulated separately (Tables 2 through 8) and included in the discussion of the immobilization study.

1.3.1 Torsion Data

1.3.1.1 General Equipment

All tests were performed on the same machine, an Instron TTD materials testing machine, with the same associated electronic equipment. Load cell output was recorded by a Honeywell 2106 Visicorder. Since the Instron TTD requires approximately 1/4-second to attain maximum velocity, it was necessary to include in each test a method of mechanically delaying the application of the load to the specimen.

The torsional load apparatus consisted of seven basic parts: (1) the Instron torsional loading assembly with Jacobs chuck; (2) the torsional delay apparatus; (3) the lower specimen mounting pot; (4) the mounted specimen; (5) the upper specimen mounting pot; (6) the mounting pot-load cell interface; and (7) the Instron torsional load cell with Jacobs chuck.

1.3.1.2 Specimen Preparation

The tibiae, femora, and humeri were dissected and mounted for testing. In order to securely grip the bones, both ends of each bone were mounted in methyl methacrylate. A special mounting jig was designed and built for this purpose. This apparatus insured that all bones were mounted uniformly with the longitudinal axis of each bone through the center of the mounting pots.

The methyl methacrylate was prepared and the torsional mounting pots sprayed with silicone spray to insure ease of removal after the acrylic had hardened. When the acrylic had reached the consistency of putty, it was poured into the grips. Then the towels were removed from the bones which had earlier been placed in the mounting apparatus, and the grip-acrylic combinations pushed onto the ends of the bones. The acrylic was hand-packed around each bone end and the Ringer's solution-soaked towels replaced. Within 15 to 20 minutes after packing, the acrylic had hardened enough to permit the potted bones to be

removed from the grip to individual bags of Ringer's solution. The bones were stored at 4°C overnight and tested the following day. Prior to testing, the bones were brought to room temperature --approximately 23°C. Precautions against drying were taken as described earlier.

1.3.1.3 Testing

Following the procedure detailed earlier, each specimen was prepared and placed into the torsional loading device. The specimen was then twisted externally at an angular velocity of 1.12 revolutions per second which produced ultimate failure in less than 100 milliseconds.

1.3.1.4 Failure Criteria for Torsion

A typical torsional load-deformation curve is presented in Figure 2. Points of interest are y_1, the maximum linear load, and x_1, the rotation to maximum linear load; y_2, the maximum load, and x_2, the rotation to failure. The maximum linear load was determined by drawing a line tangent to the linear region of the load-deflection curve and recording the load at the point where the trace departed from the line. Energy to maximum linear load was determined by measuring the area under the curve to x_1. The energy to failure was determined by measuring the area under the curve to x_2.

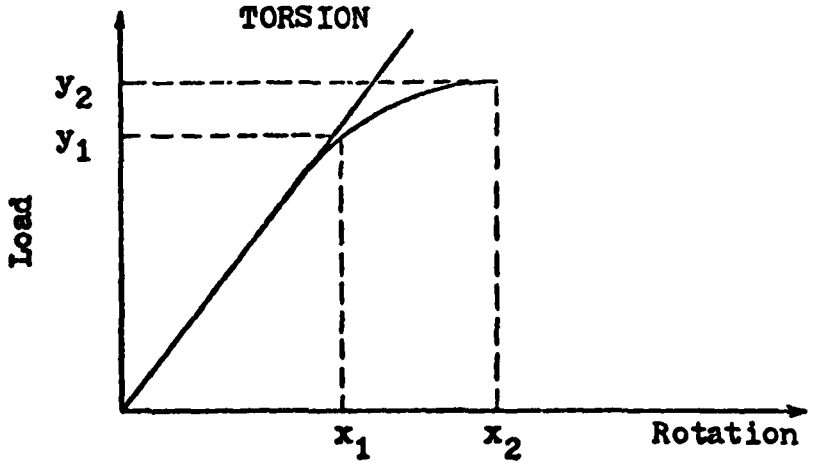

Figure 2. A Typical Torsional Load-Deformation Curve.

1.3.2 Ash Data and Chemical Data (Work Performed at FRI)

After appropriate defatting by chloroform-methanol treatment the bones were ready for volume measurements using the Archimedes principle. Calibration was achieved by using high

quality volumetric pipettes; later, Plexiglass cubes were also used for routine volume checks. Additional checks were run by performing underwater weighings with an H15 Mettler balance. Repeated measurements were within ±0.6%. Each bone was measured at least three times. The distilled water in the device contained approximately 1% of BRIJ (a nonionic detergent) which lowered the bone surface tension. A vibrator was used to remove trapped air in the marrow spaces of fractured bones. All fractured bone samples were prepared in such a way that the water would easily fill the marrow space. All whole bones and vertebral bodies were carefully checked for space quality; the majority of these bones (and all vertebral bodies) required a paraffin coating in order to get an accurate peripheral volume measurement. The paraffin was rubbed in to make the film as thin as possible. Some specimens had to be weighted down in the measuring cylinder because of their low specific weight. The paraffin was removed by extraction with benzene in a vacuum bottle.

Fat free dry weight (referred to as "dry weight") was measured after drying the bones at 105-110°C for 24 hours, soaking them again in chloroform-methanol, air-drying, and then weighing them. This was done repeatedly until two weighings agreed within less than 5 mg.

Ash weight was obtained after two to five days of heating at 600°C. The ashed bone samples were cooled in a desiccator before weighing.

Calcium was measured with a Perkin-Elmer Atomic Absorption Spectrophotometer, Model 290B. Bone samples were dissolved in HCl, diluted with lanthanum oxide and measured. A 0.1 molar calcium standard solution was used for calibration.

Magnesium was measured with the same atomic absorption spectrophotometer and in the same acid-diluted samples using the appropriate wavelength.

Inorganic phosphorus was analyzed according to Fiske and Subbarow (1925).[1]

1.3.3 Histological Data (Work Performed at HFH)

Thin sections of the tibiae, femora, and fibulae of each animal used in the study were prepared according to the manner described by Schock, Noyes, and Villanueva.[2] The sections were taken at the same relative location on each bone. Each section was orthogonal to the long axis of the bone from which it was taken. The histological measurements and

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[1] Fiske, C. H. and Y. Subbarow, 1925, J. Biol. Chem. 66, 375.

[2] Schock, C. C., F. R. Noyes, and A. R. Villanueva, 1972, Measurement of Haversian Bone Remodeling by Means of Tetracycline Labeling in Rib of Rhesus Monkeys, Henry Ford Hospital Medical Journal, 20, 3, 131-144.

calculations described by Schock, Noyes, and Villanueva (1972) were performed on the thin sections. A few additional histological quantities were also obtained from the thin sections using similar techniques.

1.4 DATA TREATMENT

1.4.1 Analysis of Variance and Range Test

Data were collected for a quantity under study* and was analyzed to determine if statistically significant differences in that quantity were present among the following test groups:

a. Control (C)
b. Immobilized (I)
c. Exercised Right (ER)**
d. Exercised Left (EL)**
e. Reconditioned Five Months (R_5)
f. (in some cases) Reconditioned 12 Months (R_{12}).

The average of the quantity under investigation was calculated for each test group and the statistical procedure called a one-way analysis of variance was used to determine whether the observed differences in the means of the various test groups indicated that a real difference existed. The technique of analysis of variance was used because it provided a single statistical test to determine if there were any real differences among the means of the various test groups.

The analysis of variance test resulted in the calculation of an F-statistic. If the F-statistic was close to 1, then there was probably no real difference among the test groups; the mean quantity calculated for each test group was not significantly different from any of the other group means for that quantity. The larger the value of the F-statistic, the more evidence the data gave that there were real differences present amoung the test groups. An F-statistic larger than the critical value of F (obtained from tables) is called a statistically significant result.

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* (e.g., maximum linear load, volume, calcium-to-magnesium ratio, etc.). A complete list of all the quantities analyzed can be found in Table 1.

** In some instances, only one test group of "exercised" monkeys was used. In these cases, only the monkeys' right legs were exercised, but the data were presented labeled simply as "E" rather than "ER".

TABLE 1

QUANTITIES ANALYZED VIA ANALYSIS OF VARIANCE AND RANGE TEST

1. maximum linear load
2. maximum load
3. rotation to maximum linear load
4. rotation to failure
5. energy to maximum linear load
6. energy to failure
7. volume
8. dry weight
9. ash weight
10. density
11. ash content
12. percent ash
13. calcium weight to volume ratio
14. calcium weight to dry weight ratio
15. phosphorus weight to volume ratio
16. phosphorus weight to dry weight ratio
17. magnesium weight to volume ratio
18. magnesium weight to dry weight ratio
19. calcium weight to phosphorus weight ratio
20. calcium weight to magnesium weight ratio
21. cortical area
22. cortical area to total area ratio
23. number of osteoid seams per unit area
24. number of resorption spaces per unit area
25. circumference of osteoid seams
26. appositional rate
27. radial closure rate
28. activation frequency
29. osteon formation time
30. resorption to formation ratio

TABLE 1 (Concluded)

QUANTITIES ANALYZED VIA ANALYSIS OF VARIANCE AND RANGE TEST

31.	bone formation rate (surface based)
32.	bone formation rate (volume based)
33.	width of osteoid seam
34.	percent labeled system
35.	percent no activity
36.	percent resorption
37.	percent formation
38.	wall thickness of completed osteon
39.	perimeter
40.	mean cortical thickness

An analysis of variance that resulted in a statistically significant F-statistic meant that the data gave real evidence that all test groups did not have the same mean value for the quantity in question.

When a significant F-statistic was obtained in the analysis of variance procedure, it was useful to determine which of the test groups differed from the others. This was accomplished by using a multiple range test. The multiple range test showed which of the test groups showed a significantly different mean for the quantity under consideration. This statistical analysis was performed for each of the quantities listed in Table 1. The results of these statistical procedures are summarized in Tables 2 through 8 in Section 2.

For a discussion of the computer programs used in this analysis, see Appendix B.

1.4.2 Correlation Matrix

A correlation matrix for the fractured bones' torsion, ash, and chemical quantities was constructed. The correlation matrix is an array that displays the individual correlation coefficients for all quantities taken two at a time. The magnitude of the correlation coefficient indicates the amount of linear relationship between the two variables. A correlation coefficient of zero indicates no linear relationship and a coefficient of one, a perfect linear relationship.

The correlation matrix was calculated as an aid in a preliminary determination of which parameters were related to each other and which relationships seemed to be the strongest.

For a discussion of the computer program used in this analysis, see Appendix A.

1.4.3 Linear Regression Analysis

In analyzing the fractured bone data, the method of linear regression was used to investigate the linear relationship between maximum load and as many as ten other quantities. These variables were volume, dry weight, ash weight, density, ash content, percent ash (i.e., the six "ash quantities"), captivity, preweight, received weight, and post-weight. The linear relationship between maximum load and each of the first eight of these quantities was investigated for each test group; post-weight was not correlated with maximum load in the control group; received weight was correlated with maximum load only in the reconditioned group. Also, linear regression analyses were performed for rotation to failure and each of the ash quantities, and for energy to failure and each of the ash quantities. A linear equation was fitted to the data using the method of least squares. The slope and intercept of the fitted line were tested

by using a t-test to determine whether they were significantly different from zero.

The correlation coefficients between maximum load and each of the other quantities were calculated. The correlation coefficients between rotation to failure and each of the ash quantities, and those between energy to failure and each of the ash quantities were also calculated. The square of the correlation coefficient can be interpreted as the percentage of variability in one variable that can be accounted for by its linear relationship with the other variable. The correlation coefficient was then tested using a t-test to determine whether it was significantly different from zero. A zero correlation coefficient is equivalent to a zero slope in the last squares line; hence, the two t-tests are the same. The results of these analyses are presented in Tables 9, 10, and 11 (Section 2.6). For a discussion of the computer programs used in these analyses, see Appendix C.

SECTION 2
DISCUSSION

2.1 FRACTURED BONE DATA

2.1.1 Torsion Data (Table 2a)

An analysis of the data indicated that the behavior of the specimens followed one of two patterns, referred to as A and B. The difference in the two behavior patterns is dependent on the specimens' response to reconditioning.

In pattern A, significant decreases were observed from the control group (C) to the immobilized group (I) and from C to the exercised group (E), while significant increases were observed from I to the five-month reconditioned group (R_5), and E to R_5. (Because the group with the right leg exercised (ER) vs. the group with the left leg exercised (EL) in no case showed any significant difference, we assumed that ER=EL=E.) This pattern indicated that immobility and/or exercise of only one leg caused a decrease in the magnitude of the torsional property but that this value returned to normal levels following a period of reconditioning. The same pattern was observed in the behavior of all three bones tested for the properties of maximum load (ML) and maximum linear load (MLL) and for the property of energy to maximum linear load (EMLL) in the femur and the humerus.

In pattern B, significant decreases were observed from C to I, C to E, and C to R_5. No significant increases were observed. This pattern also indicated that immobility and/or exercise of only one leg caused a decrease in the value of the

TABLE 2a

FRACTURED BONES, TORSION DATA

	C vs. I	C vs. ER	C vs. EL	C vs. R_5	I vs. ER	I vs. EL	I vs. R_5	ER vs. EL	ER vs. R_5	EL vs. R_5
	TIBIA									
MLL	**↓	**↓	*↓				**↑		**↑	*↑
ML	**↓	**↓	**↓				**↑		*↑	*↑
RMLL	**↓	***↓	***↓	***↓						
RFL	***↓	***↓	***↓	***↓						
EMLL	***↓	***↓	***↓	**↓						
EFL	***↓	***↓	***↓	***↓						
	FEMUR									
MLL	***↓	**↓	***↓				***↑		***↑	***↑
ML	***↓	**↓	**↓				***↑		***↑	***↑
RMLL										
RFL				*↓			*↓			
EMLL	***↓	***↓	***↓				**↑		**↑	*↑
EFL										
	HUMERUS									
MLL	***↓	**↓		*↑	*↑		***↑		***↑	
ML	***↓	**↓			*↑		***↑		***↑	
RMLL										
RFL										
EMLL	***↓	*↓			*↑		***↑		*↑	
EFL										

Arrows indicate the direction of the second treatment's effect with respect to the first treatment's values.

torsional property but that the five-month reconditioning period did not effect a recovery to normal values of the property. This pattern was observed only in the tibia for the properties of rotation to maximum linear load (RMLL), rotation to fail (RFL), EMLL, and energy to fail (EFL). Also, although the data for EFL for the femur did not show statistical significance, significance was approached at the 0.05 level in the B pattern.

The humerus showed a slight variation of pattern A for MLL, ML, and EMLL. The same significant differences as those described were observed, with the addition of a significant increase from I to E, and in the case of MLL, an increasing trend from C to R_5. These additional increasing trends are consistent with the original interpretation of pattern A if the relative magnitudes of the changes are taken into account. In the case of the humerus, exercise did not cause as large a decrease in the values of these torsional properties as it did in the tibia and femur, where the effects of "exercise" were indistinguishable from those of immobilization. This was seen statistically as an increase from I to E. The increase from C to R_5 merely indicated a particularly successful reconditioning, the reconditioned specimens being stronger than the controls.

The behavior of EMLL conformed to a strong B pattern for the tibia but showed a definite A pattern for the femur and the humerus; conversely, EFL showed a strong B pattern for the tibia and tended toward a B pattern for the femur, while for the humerus, EFL approximated pattern A behavior. Also, the tibia, except for MLL and ML, exhibited strong B pattern behavior for all its properties, while for the femur and humerus, RMLL and RFL showed no pattern whatsoever.

One possible explanation is that the properties of ML and MLL have a relatively high recovery rate in all bones; they showed pattern A behavior in all three bones tested. EMLL and EFL have the next highest recovery rate. The humerus generally recovers all its torsional properties at a higher rate than the tibia, which recovers at the lowest rate, and the femur, which responds to reconditioning at a rate intermediate to that of the humerus and the tibia. Reconditioning actually raised some values to greater than control values for the humerus. Also, the humerus maintained its torsional properties to some degree with exercise, which the tibia and femur did not. This accounts for the fact that after five months of reconditioning, the EMLL and EFL behaved according to an A pattern in the humerus, while the femur showed a mixed pattern of behavior for these quantities, and a definite B pattern was evident for EMLL and EFL in the unrecovered tibia.

The values of the bones' mechanical properties decreased at rates inversely proportional to their rates of recovery for those properties. Thus, RMLL and RFL decreased

rapidly for the tibia and recovered slowly. For the femur and humerus, which generally recover their properties more quickly, RMLL and RFL did not seem to be affected by immobilization and/or "exercise"; i.e., no significant loss occurred, therefore no recovery was noticeable. Any decrease in RMLL or RFL occurred at a slower rate and, therefore, was smaller for the femur and humerus than for the tibia.

In terms of rapid rate of property decrease and slowness of recovery, tibia>femur>humerus. This phenomenon could be called "bone effect." In terms of properties decreasing most rapidly and most slowly recovered, RFL and RMLL>EFL and EMLL>ML and MLL. This phenomenon could be called "property effect." In some cases the "bone effect" was stronger than the "property effect" and vice versa. For example, the femur decreased in RFL and RMLL more slowly and recovered them more rapidly than the tibia decreased in and recovered ML and MLL. In the former case, the "bone effect" dominated; in the latter, the "property effect" was dominant.

In an attempt to explain these losses and recoveries of properties, the ash and chemical data were studied.

2.1.2 Ash Data (Table 2b)

The volume, dry weight, and ash weight of the femur behaved according to the B pattern (see torsion data discussion); i.e., immobilization and/or exercise of only one leg caused decreases in these values. They did not regain control levels after five months of reconditioning. These values for the humerus appeared to exhibit A behavior: they decreased after immobilization and/or exercise of only one leg; however, a five-month reconditioning period effected the return of these values to their control levels. For the tibia, definite decreases in dry and ash weight were effected by immobilization and/or exercise of only one leg but the effects of reconditioning were not apparent.

As mentioned in the discussion of the torsion data, exercise appeared to mitigate the effects of immobilization in the humerus but not in the tibia or the femur. This is mentioned because, for humerus volume, and in some cases for the humerus torsion data (Table 2a), E increased with respect to I. Such an increase was not inconsistent with pattern A behavior. Moreover, when E increased with respect to I, it was consistent with pattern A behavior for R_5 not to have increased with respect to E; i.e., when the "exercise" treatment prevented a large drop from the C values, the reconditioning process did not cause a statistically significant increase from E values.

Density and ash content values showed no significant differences from treatment to treatment for any of the three bones. Since these two values were the ratios of, respectively, dry weight to volume and ash weight to volume, we assumed that the observed

TABLE 2b

FRACTURED BONES, ASH DATA*

	C vs I	C vs ER	C vs EL	C vs R_5	I vs ER	I vs EL	I vs R_5	ER vs EL	ER vs R_5	EL vs R_5
	TIBIA									
Vol										
DryWt	*↓	*↓	*↓	*↓						
AshWt	*↓	*↓	*↓							
Density										
Ash Con										
% Ash										
	FEMUR									
Vol	***↓	*↓	*↓	*↓						
DryWt	***↓	**↓	**↓	*↓						
AshWt	***↓	**↓	**↓	*↓						
Density										
Ash Con										
% Ash										
	HUMERUS									
Vol	***↓	**↓			*↑		***↑			
DryWt	***↓	***↓					***↑		**↑	
AshWt	***↓	***↓					***↑		**↑	
Density										
Ash Con										
% Ash					*↑		*↑			

* Data obtained at FRI

Arrows indicate the direction of the second treatment's effect with respect to the first treatment's values.

decreases in the quantities of volume, dry weight, and ash weight occurred at about the same rate and were about the same size. Further support for this assumption lay in the fact that percent ash showed no pattern of significant differences for the tibia and femur; therefore, the quantities of dry weight and ash weight must have decreased at a similar rate and magnitude. The increases from I to E and from I to R_5 observed for humerus percent ash indicated that exercise during both immobilization and reconditioning caused ash weight to increase at a greater rate and/or with a greater magnitude than dry weight.

The ash data did not exhibit any "property effects" affecting recovery to control values. Behavior of recovery according to the A or B pattern seemed to be dependent entirely upon the bone type.

Since ML and MLL results always conformed to pattern A, these two torsional values did not appear dependent upon volume, dry weight or ash weight, because these three variables behaved according to either pattern A or B, depending upon bone type.

In general, recovery of ash data to control values lagged behind recovery of torsional data to control values.

2.1.3 Chemical Data (Table 2c)

The ratios of magnesium to dry weight and magnesium to volume showed no significant differences from treatment to treatment for any of the bones. This indicated that magnesium levels rose and fell at the same rate and with the same relative magnitude as volume and dry weight during immobilization and reconditioning.

A pattern of significant differences consistent from bone to bone was observed for the ratio of calcium to magnesium. For each bone tested, significant decreases were observed from C to I, C to E, and C to R_5. This ratio seemed to decrease quickly upon immobilization and the decrease was not mitigated by exercise, nor did the five-month reconditioning period effect a return of the ratio to C levels. Since the ratios of calcium to volume, calcium to dry weight, magnesium to volume, and magnesium to dry weight never decreased significantly from C to I, it seemed inconsistent that the ratio of calcium to magnesium always decreased significantly from C to I. This could be explained if the calcium weight decreased at a slightly more rapid rate than volume and dry weight, while magnesium decreased at a slightly slower rate than volume and dry weight.

The behavior of calcium weight in the humerus showed a pattern different from that shown in either the tibia or femur. The ratios of calcium to volume and to dry weight showed decreases from C to E, I to E, and R_5 to E. Also, the

TABLE 2c

FRACTURED BONES, CHEMICAL DATA *

	C vs I	C vs ER	C vs EL	C vs R_5	I vs ER	I vs EL	I vs R_5	ER vs EL	ER vs R_5	EL vs R_5
TIBIA										
Ca/DrWt				*↓						
Ca/Vol				**↓						
P/DrWt										
P/Vol										
Mg/DrWt										
Mg/Vol										
Ca/P										
Ca/Mg	*↓	*↓	*↓	**↓						
FEMUR										
Ca/DrWt										
Ca/Vol		*↓	*↓							
P/DrWt										
P/Vol		*↓	**↓							
Mg/DrWt										
Mg/Vol										
Ca/P										
Ca/Mg	**↓	**↓	**↓	*↓						
HUMERUS										
Ca/DrWt		***↓			**↓				* ↑	
Ca/Vol		***↓			**↓				* ↑	
P/DrWt										
P/Vol					*↓					
Mg/DrWt										
Mg/Vol										
Ca/P	*↓	***↓		*↓	*↓					
Ca/Mg	*↓	***↓		*↓	*↓					

* Data collected at FRI.

- Arrows indicate the direction of the second treatment's effect with respect to the first treatment's values.

calcium to phosphorus ratio and calcium to magnesium ratio both showed a pattern of significant decreases not only from C to I, C to E, and C to R (these decreases were also seen in the calcium to magnesium ratio for the tibia and femur) but also from I to E. This suggested that the humerus calcium weight decreased more rapidly and/or to a lower value during complete immobilization than tibia or femur calcium weight, since it must have decreased at a greater rate and/or to a lower value with respect to phosphorus than it did in the other bones. Phosphorus behavior from bone to bone was fairly consistent; therefore, the unique behavior of humerus calcium to phosphorus ratios was probably due to a difference in the behavior of humerus calcium. More interesting, however, was the observation that exercise of one leg exacerbated the decline in calcium weight.

2.2 WHOLE BONE ASH AND CHEMICAL DATA (Table 3)

The ash and chemical data for the whole bones showed few trends in the significant differences from treatment to treatment. However, the tibia chemical data exhibited a significant decrease from C to I for the phosphorus to dry weight ratio and significant increases from C to I for the ratios of calcium to both phosphorus and magnesium. These significant differences could have been caused by a slight decrease in phosphorus weight during immobilization coupled with either a similar decrease in magnesium weight or a slight increase in calcium weight during immobilization. Since these increases and decreases were not observed elsewhere, they are probably indicative of no clearcut trend.

Only the femur and the humerus ash data exhibited any of the effects associated with immobilization and reconditioning in the data presented. The femur showed a significant decrease from C to I for both dry and ash weight, and significant increases from C to R_{12} and I to R_{12} for the same two variables. Also observed was an increase in volume from I to R_{12}. The humerus displayed significant increases from C to R_{12} and I to R_{12} for dry weight, ash weight, and percent ash. In summary, the femur showed a pattern of recovery of these two quantities upon reconditioning. The humerus' gain in dry and ash weight upon reconditioning could not properly be termed "recovery" since no significant decrease in the two weights was observed during immobilization. The humerus recovered ash weight more rapidly and/or to a greater extent than dry weight (i.e., percent ash increased); the femur did not exhibit the same behavior.

Neither the femur nor the humerus showed any significant differences from treatment to treatment in their chemical data. Any loss of calcium, phosphorus, or magnesium occurred at about the same rate as the loss of dry and ash weight within each bone. None of the three elements measured showed any change with respect to volume. Volume showed no significant differences from treatment to treatment. Therefore, the change in dry and

TABLE 3

WHOLE BONES, ASH DATA, AND CHEMICAL DATA*

TIBIA

	C vs I	C vs R_{12}	I vs R_{12}		C vs I
Vol				CaDrWt	
DrWt				Ca Vol	
A Wt				PDrWt	*↓
Dens				P Vol	
A Con				MgDrWt	
% A				Mg Vol	
				Ca/P	*↑
				Ca/Mg	*↑
	FEMUR				
Vol			* ↑	CaDrWt	
DrWt	*↓	***↑	***↑	Ca Vol	
A Wt	*↓	***↑	***↑	PDrWt	
Dens				P Vol	
A Con				MgDrWt	
% A				Mg Vol	
				Ca/P	
				Ca/Mg	
	HUMERUS				
Vol				CaDrWt	
DrWt		**↑	**↑	Ca Vol	
A Wt		***↑	**↑	PDrWt	
Dens				P Vol	
A Con				MgDrWt	
% A		* ↑	* ↑	Mg Vol	
				Ca/P	
				Ca/Mg	

* Data collected at FRI.

No significant differences from treatment to treatment existed for any of the ash or chemical values for the radius, fibula, and ulna. Arrows indicate the direction of the second treatment's effect with respect to the first treatment's values.

ash weight associated with the experimental treatments must have been slight, since the three elements showed no change relative to ash and dry weight, which were quantities that changed significantly, nor did they change relative to volume, a quantity which showed no significant change.

The absence of decreasing from C to I in the ash data for the whole bones was interesting. Such decreases were strong for the fractured bones' dry weight, ash weight, and volume (Table 2b). Presumably, the two weights were measured according to the same procedure for both the whole and fractured bones. The specimens themselves were treated identically except for the torsional fracture of the fractured bones, and this treatment would not cause the decrease from C to I in the weights of those specimens. The discrepancy between the whole and fractured bones' volume data may be more easily explained. For the whole bones, the volume measurements included the volume of the medullary canal; the fractured bones' did not include the medullary canal. Therefore, the data may indicate that loss of bone volume during immobilization occurs because of a loss of endosteal bone while the initial external perimeter of the bone is maintained.

2.3 SMALL BONE ASH AND CHEMICAL DATA (Tables 4a and 4b)

For density, ash content, and percent ash (Table 4a), as well as for all of the chemical quantities (Table 4b), results represent ratios. Therefore, for one of these quantities,

(1) A ↑ may signal either

  (a) a net increase in the numerator
  (b) a net decrease in the denominator

(2) A ↓ may signal either

  (a) a net decrease in the numerator
  (b) a net increase in the denominator

For the "ratio quantities" the denominator is always either volume or dry weight, with the two exceptions of the calcium to phosphorus and the calcium to magnesium ratios. To simplify the discussion, certain generalizations about the behavior of volume and dry weight were made. Then attempts were made to explain the behavior of the other variables.

For the talus, immobilization caused volume to drop. Only the values C and I showed any significant difference. However, neither C nor I values were significantly different from E values, nor were C or I values significantly different from R values. (The term "R" is used when the statement applies to both R_5 and R_{12} values.) An inspection of the means of the talus volumes (Appendix D, Table 33) permits an explanation for this apparent paradox. Exercise seems to have mitigated the effect of

TABLE 4a

SMALL BONES, ASH DATA *

TALUS

	C vs I	C vs ER	C vs EL	C vs R_5	C vs R_{12}	I vs ER	I vs EL	I vs R_5	I vs R_{12}	ER vs EL	ER vs R_5	ER vs R_{12}	EL vs R_5	EL vs R_{12}	R_5 vs R_{12}
Vol	**↓														
DrWt	***↓	***↓	***↓	***↓	*↑				***↑			***↑		***↑	***↑
A Wt	***↓	***↓	***↓	***↓					***↑			***↑		***↑	**↑
Dens		**↓	*↓						**↑			***↑		***↑	* ↑
A Con	* ↓	**↓	**↓						***↑						
% A															

CALCANEUS

	C vs I	C vs ER	C vs EL	C vs R_5	C vs R_{12}	I vs ER	I vs EL	I vs R_5	I vs R_{12}	ER vs EL	ER vs R_5	ER vs R_{12}	EL vs R_5	EL vs R_{12}	R_5 vs R_{12}
Vol	***↓								* ↑						
DrWt	***↓	***↓	***↓	***↓					***↑			***↑		***↑	***↑
A Wt	***↓	***↓	***↓	***↓					***↑			***↑		***↑	***↑
Dens	* ↓	**↓	**↓		*↑				***↑			***↑		***↑	***↑
A Con	* ↓	* ↓	* ↓		*↑				***↑						
% A															

* Data collected at FRI.

Arrows indicate the direction of the second treatment's effect with respect to the first treatment's values.

TABLE 4a (concluded)

SMALL BONES, ASH DATA*

ULNA

	CvsI	CvsE	CvsR$_5$	IvsE	IvsR$_5$	EvsR$_5$
Vol						
DrWt			*↑			
A Wt			*↑			
Dens					**↑	
A Con	*↓				**↑	
% A						

METATARSAL I

MT I	CvsI	CvsER	CvsEL	CvsR$_5$	IvsER	IvsEL	IvsR$_5$	ERvsEL	ERvsR$_5$	ELvsR$_5$
Vol		**↓		**↓	**↓		**↓			
DrWt				**↓			**↓			
A Wt				**↓			**↓			
Dens		***↑			***↑			***↓	***↓	
A Con		***↑			***↑			***↓	***↓	
% A										*↓

* Data collected at FRI.

Arrows indicate the direction of the second treatment's effect with respect to the first treatment's values.

TABLE 4b

SMALL BONES, CHEMICAL DATA*

TALUS

	C vs I	C vs ER	C vs EL	C vs R_5	I vs ER	I vs EL	I vs R_5	ER vs EL	ER vs R_5	EL vs R_5
CaDrWt										
CaVol										
PDrWt										
PVol										
MgDrWt										
MgVol										
Ca/P										
Ca/Mg										

CALCANEUS

	C vs I	C vs ER	C vs EL	C vs R_5	I vs ER	I vs EL	I vs R_5	ER vs EL	ER vs R_5	EL vs R_5
CaDrWt										
CaVol	*↓	*↓	**↓	*↓						
PDrWt										
PVol	**↓	***↓	***↓	*↓						
MgDrWt										
MgVol	**↓	**↓	***↓							
Ca/P										
Ca/Mg										

ULNA

	C vs I		C vs E	C vs R_5		I vs E	I vs R_5			E vs R_5
CaDrWt						**↓	*↓			
CaVol										
PDrWt	*↓									
PVol	**↓						**↑			
MgDrWt						*↑				
MgVol	*↓					*↑	*↑			
Ca/P	**↑					***↓	**↓			
Ca/Mg	*↑					***↓	**↓			

METATARSAL I

	C vs I	C vs ER	C vs EL	C vs R_5	I vs ER	I vs EL	I vs R_5	ER vs EL	ER vs R_5	EL vs R_5
CaDrWt										
CaVol		***↑			***↑			***↓	***↓	
PDrWt										
PVol		***↑			***↑			**↓	***↓	
MgDrWt										
MgVol		***↑			***↑			***↓	***↓	
Ca/P										
Ca/Mg										

* Data collected at FRI.

Arrows indicate the direction of the second treatment's effect with respect to the first treatment's values.

immobilization for the talus only slightly; the mitigation was sufficient to prevent a statistically significant difference from appearing between C and E but not enough to cause a significant difference between I and E. The values for the volumes of tali from reconditioned animals showed similar trends. Reconditioning for both five and 12 months caused an increase in the volume of these specimens as compared to the immobilized volumes but while the increase was large enough to prevent a statistical difference between C and R, it was not sufficient to cause a significant difference between I and R. Therefore, it is not surprising that E and R values were not significantly different. Although R_5 and R_{12} volumes were not significantly different, R_{12} had a mean larger than that of R_5. It seems reasonable to conclude that the talus volume decreased upon immobilization, that exercise mitigated this decrease, and that recovery to near-control levels was effected by 12, and possibly even by five, months of reconditioning.

Dry weight and ash weight fit into the A pattern described (see discussion of FRACTURED BONES, TORSION DATA, and Table 2a) but only because 12-month reconditioning values were included. Were there no R_{12} data, dry weight and ash weight would have corresponded to pattern B; i.e., no evidence of recovery was evident after five months of reconditioning. After 12 months, however, reconditioning caused dry weight to achieve, and ash weight to surpass the control values. Consistent with this is the significant increase from R_5 to R_{12}. Thus, the recovery behavior of talus ash weight and dry weight differed from that of talus volume. All three quantities appeared to be lost at approximately the same rate during immobilization. Reconditioning effected a gradual recovery of volume which began immediately. The ash weight and dry weight, however, remained depressed until sometime after five months of reconditioning, then increased rapidly, reaching control or greater than control levels after 12 months of reconditioning.

Density is a ratio of dry weight to volume. The fact that C and I values showed no significant difference is consistent with the suggestion that both dry weight and volume of the talus were lost at about the same rate and/or magnitude during immobilization. Exercised values were not significantly different from immobilized values; however, they were significantly different from control values. This might have been due to the fact that the exercised bone volumes were intermediate between the control volumes and immobilized volumes and were not significantly different from either. At the same time, exercised and immobilized bone dry weights were about the same, and both were significantly lower than the control dry weights. Comparing I densities to E densities was identical to comparing those two ratios (i.e., I and E) of dry weight to volume, where both dry weights were about equal, but the E volume was slightly greater than the I volume. This caused E density to be less than I density but not significantly so (since E volume was not significantly greater than I volume).

However, E density was significantly less than C density. This was due to E volume not being significantly different from C volume, while E dry weight was significantly less than C dry weight. Since volume recovered at a slower rate than dry weight during the period from the fifth to the 12th month of reconditioning, it was not surprising that significant differences in densities were shown between I and R_{12}, E and R_{12}, and R_5 and R_{12}. All of these categories showed a significant upward change in dry weight with no significant change in volume; therefore, densities increased. Since density increased significantly from R_5 to R_{12}, recovery must have been occurring, and because neither C vs. R_5 nor C vs. R_{12} showed significant differences in densities, the density at R_5 must have been less than that of C. The C density was in turn less than that of R_{12}. All this is consistent with the previously expressed conclusion that the recovery of dry weight lags behind the recovery of volume, not beginning until sometime after the fifth month of reconditioning and proceeding rapidly once begun. Meanwhile, the recovery of volume begins with the onset of reconditioning and continues at a rate slower than that of dry weight, but effects approximately the same magnitude of increase in the property after (in this case) five months of reconditioning.

Ash content is the ratio of ash weight to volume. Unlike density, ash content did show a drop from C to I, indicating that ash weight fell at a higher rate and/or to a lower value than volume. The remainder of the ash content data showed the same pattern of significant differences as the density data. Since the ash weight data showed the same pattern of significant differences as the dry weight data, it was appropriate to assume that the relationships between volume and ash weight, causing the pattern of significant differences for ash content, were similar to those described for volume and dry weight.

Percent ash is the ratio of ash weight to dry weight. This ratio, for the talus, did not seem to be significantly affected by immobilization or reconditioning. Thus, it was reasonable to expect that ratios of the weights of calcium, magnesium, or phosphorus to bone dry weight would not be affected by the experimental treatments. The chemical data for the talus were consistent with this expectation: none of these ratios showed any significant differences from treatment to treatment.

The significantly greater value for R_{12} compared to C, which was present in the ash weight data and not in the dry weight data, was not inconsistent with the previously discussed behavior since it indicated only that reconditioning had been especially effective in recovery of dry weight. However, reconditioning did cause some significant recovery for both ash weight and dry weight. Ash weight recovered from the low immobilized levels to levels equal to control levels, and dry weight recovered from immobilized levels and increased to levels significantly greater than the controls.

Further examination of the chemical data for the talus showed that the ratios of calcium, magnesium, and phosphorus to volume remained constant despite experimental treatment. This was unexpected because ash content showed a pattern of decrease due to immobilization, with recovery upon reconditioning, suggesting that a similar pattern of significant changes would exist for these ratios. One possible explanation is that, while calcium, magnesium, and phosphorus levels did fall during immobilization, (they must have fallen because the three ratios of calcium, magnesium, and phosphorus to volume remained constant, and volume fell significantly during immobilization) their rate of decrease was only slightly greater than that of volume; or the magnitude of decrease was, relative to that of volume, only slightly greater. Thus, no significant differences were ever observed for the ratios of each element to the bone volume. However, the cumulative mineral weight, reflected in the quantity "ash weight," showed a significant decrease relative to the decrease in volume. Therefore, the data for talus ash content showed a pattern of significant differences indicating a decrease due to immobilization and recovery upon reconditioning.

Calcium to phosphorus and calcium to magnesium ratios of the talus were significantly affected by the experimental treatment.

The ash data for the calcaneus showed patterns of significant differences from treatment to treatment which were very similar to those shown in the ash data for the talus. There were only five instances where the pattern of significant differences for the talus ash data did not match that pattern for the calcaneus ash data, and none of these discrepancies was inconsistent with the patterns of behavior due to immobilization and reconditioning proposed for each variable in the discussion of the talus ash data.

The first discrepancy was in the calcaneus volume data, where R_{12} was significantly larger than the immobilized value. For the talus, there was no significant difference between I and R_{12}. This indicated that the calcaneus volume recovered somewhat more quickly than that talus volume; however, recovery was still gradual, because although C and R_{12} showed no significant difference, neither did C and R_5, R_5 and R_{12}, E and R_5, I and R_5, nor I and E. All this implied that the values for E, R_5, and R_{12} were spaced about evenly in ascending order between a low value of I and a high value of C. This indicated that reconditioning caused or brought about continuous and gradual recovery of calcaneus volume, rather than a sudden, rapid recovery of the quantity.

The second discrepancy between the calcaneus and the talus ash data was the absence of a significant difference between C and R_{12} values for ash weight. This implied that calcaneus ash weight did not recover upon reconditioning as rapidly or to as great an extent as talus ash weight.

Two additional discrepancies were found in the density data. There was a significant decrease from C to I and a significant increase from C to R_{12} in the calcaneus data, but not in the talus data. This indicated that the calcaneus dry weight decreased faster and/or further with respect to volume than the talus dry weight. Also, the calcaneus density recovered to a value greater than the control value more rapidly than the talus density. The same was true of the calcaneus ash content with respect to the talus ash content, which accounts for the final discrepancy.

The calcaneus chemical data exhibited decreases from C to I and C to E for the ratios of calcium to volume, phosphorus to volume, and magnesium to volume. In addition, the ratios of calcium to volume and phosphorus to volume decreased from C to R_5. Calcaneus calcium, phosphorus, and magnesium weights probably decreased from control levels due to immobilization and/or exercise of only one leg, remained depressed for five months of reconditioning, and returned to control values after 12 months of reconditioning because dry weight exhibited this behavior. The three ratios of mineral weight to dry weight did not change from treatment to treatment. Calcaneus volume decreased significantly upon immobilization, exercise mitigated this decrease, and recovery was gradual, beginning soon after the initiation of reconditioning. Thus, from the onset of reconditioning until five months later, calcium and phosphorus weights were depressed further below control levels than was the volume; therefore, the ratios of calcium to volume and phosphorus to volume were depressed. Magnesium weight had evidently exhibited some recovery after five months of reconditioning because no significant difference was apparent between C and R_5 for the magnesium to volume ratio.

Talus dry weight and mineral weights probably also paralleled one another closely but did not decrease as rapidly or to levels as far below control as the calcaneus dry weight and mineral weights. Note that the talus density (i.e., the ratio of dry weight to volume) did not decrease from C to I, indicating that volume had decreased in proportion to dry weight during immobilization. The talus mineral weight to volume ratios never showed any significant differences from treatment to treatment because that bone's mineral weights, closely paralleling the behavior of dry weight, were never depressed much further below their control levels than volume was depressed below its control level.

The ulna showed a pattern of significant differences unlike that of either the talus or the calcaneus. The significant differences were difficult to explain, and seemed indicative of no clear-cut trend. Furthermore, the ulna data included in the whole bone data (Table 3) showed no significant differences in either the ash or the chemical data. There was no difference

between the treatment of the ulnas in the "whole bone" category and that in the "small bone" category, so it is unclear why significant differences should have shown up in the small bone data and not in the whole bone data. One possible explanation is that some of the sample sizes in the small bone data were too few. For example, the reconditioned group contained only four specimens. Since four out of the five significant differences observed in the ulna small bone ash data were between the reconditioned specimens and some other group, the small sample size may have contributed to observed statistical differences which were really not valid bases for meaningful interpretations.

The chemical data for the ulna showed a more interpretable pattern of significant differences, although why the "small bone ulna" data showed patterns of significant differences, while the "whole bone ulna" data showed none is unclear. The ratios of phosphorus to dry weight and phosphorus to volume decreased from C to I, as did the ratio of magnesium to volume. Since neither volume nor dry weight decreased from C to I, the decrease in these ratios apparently was due to decreases in the weights of phosphorus and magnesium. Logically then, the increases in the ratios of calcium to phosphorus and calcium to magnesium were due to the decreases in the weights of phosphorus and magnesium rather than to any increase in calcium weight. As has been observed for some other bones, exercise seemed to mitigate and reconditioning seemed to reverse the effects of immobilization. The ratio of magnesium to volume increased from I to E and I to R_5, while the ratios of calcium to phosphorus and calcium to magnesium decreased from I to E and I to R_5. The magnesium to dry weight ratio increased from I to E; the phosphorus to volume ratio increased from I to R_5. The latter increases supported the proposal that exercise mitigated and reconditioning reversed the effects of immobilization; however, the trend was not as strong as it might have been since the phosphorus to volume ratio showed no increase from I to E, and the magnesium to dry weight ratio showed no trend from I to R_5. The decreases from I to E and I to R_5 for the ratio of calcium to dry weight were consistent with those observed for the calcium to phosphorus and calcium to magnesium ratios. These decreases in calcium weight implied or suggested that a decrease in calcium was part of the mitigating and/or reconditioning process. (See also the discussion of FRACTURED BONES, CHEMICAL DATA for the humerus.)

Metatarsal I showed a confusing pattern of significant differences. For instance, density, ash content, and the ratios of calcium to volume, phosphorus to volume, and magnesium to volume all showed significant differences between EL and ER. This was reflected throughout a large portion of the data in that C, I, and R_5 were significantly different from ER but not from EL. Once again, the problem was probably due to small sample sizes since ER and EL contained two and three

specimens, respectively. The same problem also caused the odd chemical data for metatarsal I, where the only significant differences involved ER. The small sample size of R_5 (6) may also have been responsible for the unusual results observed for volume, dry weight, and ash weight of metatarsal I. All of these quantities decreased from C to R_5 and I to R_5. Since this was the only case where reconditioning caused a decrease in these quantities, the results were viewed with some suspicion.

2.4 VERTEBRAL BODY DATA (Table 5)

Only the whole body ash data showed any significant differences. For D12, there was a significant increase for both density and ash content from I to R_{12} and from E to R_{12}. The same pattern also existed for L2, except that no significant increase was present from I to R_{12} for L2's ash content. The experimental treatments caused no significant changes for the volume, dry weight, or ash weight of either body. Density and ash content are, respectively, the ratios of dry weight to volume and ash weight to volume. Thus, the increases in density and ash content could have been caused only by slight increases in dry weight and ash weight, coupled with a slight increase in volume after 21 months of reconditioning.

2.5 HISTOLOGY DATA

Typical cross-sections of long bones display three distinct concentric regions of bone. From the external surface toward the center, these regions are the periosteal, haversian, and endosteal regions. Since the histological behavior of each region is independent of the other two, the three regions are discussed separately.

2.5.1 Periosteal Histology Data (Table 6)

The tibial circumference of osteoid seams showed significant increases from C to R_{12}, I to R_{12}, and E to R_{12}. While immobilization or exercise of only one leg did not cause any change in the circumference of osteoid seams, 12 months of reconditioning resulted in an increase from control levels. Some increase in the circumference of osteoid seams occurred after only five months of reconditioning, because neither C vs. R_5 or R_5 vs. R_{12} showed a significant difference. Therefore, the R_5 values must have occurred intermediate to the significantly different C and R_{12} values.

A similar pattern was shown for tibial percent formation which exhibited increases from C to R_5, C to R_{12}, I to R_5, I to R_{12}, E to R_5, and E to R_{12}. Here again, immobilization or exercise of only one leg did not cause any change from control levels in the values of the measurements but reconditioning caused increases from control levels. In the case of percent formation, the increase due to reconditioning was more rapid than for the

TABLE 5

WHOLE VERTEBRAL BODY ASH DATA*

D12-Whole

	C vs I	C vs E	C vs R_5	C vs R_{12}	I vs E	I vs R_5	I vs R_{12}	E vs R_5	E vs R_{12}	R_5 vs R_{12}
Vol										
DrWt										
A Wt										
Dens							**↑		**↑	
A Con							**↑		**↑	
% A										
	L2-Whole									
Vol										
DrWt										
A Wt										
Dens							**↑		**↑	
A Con									**↑	
% A										

* Data collected at FRI.

The core ash data showed no significant differences. None of the vertebral body chemical data showed any significant differences. Arrows indicate the direction of the second treatment's effect with respect to the first treatment's values.

TABLE 6

PERIOSTEAL HISTOLOGY DATA*

TIBIA	C vs I	C vs E	C vs R_5	C vs R_{12}	I vs E	I vs R_5	I vs R_{12}	E vs R_5	E vs R_{12}	R_5 vs R_{12}
P										
Af										
Sf				**↑			*↑		*↑	
W.T.										
M										
Mf										
σf										
μf										
% labeled sys.			*↑	*↑						
% no activity										
% resorption										
% formation			*↑	*↑		**↑	**↑	**↑	**↑	
surface Vf										
M.C.T.	*↓	*↓					**↑		**↑	
volume Vf										

FEMUR	ER-EL	C vs I	C-ER	C-EL	C vs R_5	C vs R_{12}	I-ER	I-EL	I vs R_5	I vs R_{12}	ER-R_5	EL-R_5	ER-R_{12}	EL-R_{12}	R_5 vs R_{12}
P								*↑						*↓	
Af						***↓				*↓			*↓	*↓	
Sf															
W.T.															
M		**↓					*↑		**↑	*↑					
Mf		**↓					*↑		**↑	*↑					
σf															
μf	*↓	**↓		*↓		*↓	*↑				*↓		*↓		
% label														*↑	
% no activity						*↑									
% resorption						**↓				**↓					
% formation										*↑					
surface Vf									***↑			*↑			
M.C.T.						***↑				***↑			**↑	***↑	***↑
volume Vf					**↑				***↑			**↑			**↓

FIBULA	C vs I	C-ER	C-EL	C vs R_4	I-ER	I-EL	I vs R_4	ER vs EL	ER-R_4	EL-R_4
P										
Af										
Sf										
W.T.										
M	**↓						***↑			
Mf	**↓						***↑			
σf										
μf										
% labeled sys.							*↑			
% no activity										
% resorption										
% formation										
surface Vf	*↓						**↑			
M.C.T.										
volume Vf							**↑			

* Data collected at HFH.

circumference of osteoid seams, because both R_5 and R_{12} values showed significant increases from C, I, and E levels.

Tibial mean cortical thickness decreased significantly from C to I and C to E but increased significantly from I to R_{12} and E to R_{12}. Thus, mean cortical thickness exhibited the classical behavior pattern of decrease upon immobilization or exercise of only one leg, with recovery upon reconditioning.

The number of femoral osteoid seams per unit area was not affected by immobilization or exercise of only one leg; however, reconditioning for 12 months caused a decrease in this quantity.

Femoral mean appositional rate and radial closure rate both decreased upon immobilization and recovered to control levels upon reconditioning. Exercise of only one leg did not affect these two quantities.

Femoral activation frequency decreased upon immobilization but its response to reconditioning was unclear. While C vs. R_5 showed no significant difference, there was a significant decrease from C to R_{12}. The effect of the "exercise" treatment upon femoral activation frequency was impossible to ascertain due to the fact that ER was significantly different from EL. This was reflected throughout the results of the range test; C, I, R_5, and R_{12} were each significantly different from both ER and EL.

Reconditioning for 12 months caused a significant decrease in femoral percent resorption. However, R_{12} was not significantly lower than E or R_5, both of which showed no significant differences from either C or I. Therefore, this decrease due to reconditioning was gradual and was slightly enhanced by exercise of only one leg.

Femoral mean cortical thickness was not affected by immobilization or exercise of only one leg, nor by the 5-month reconditioning treatment. After 12 months of reconditioning, mean cortical thickness increased significantly with respect to C, I, E, and R_5 values.

The behavior of femoral volume-based bone formation rate was especially interesting. While C, I, E, and R_{12} showed no significant differences among them, R_5 was significantly greater than both C and I; R_5 was also significantly greater than EL but not ER. Yet, ER and EL were not significantly different from each other. Finally, R_{12} was significantly less than R_5; thus, although immobilization or exercise of one leg did not affect volume-based bone formation rate, reconditioning caused it to increase, reaching a peak at about five months of reconditioning. After 12 months of reconditioning, volume-based bone formation rates had returned to control levels again.

Fibular mean appositional rate, radial closure rate, and surface-based bone formation rate followed the simple pattern of decrease upon immobilization with recovery upon reconditioning. Exercise of only one leg did not affect these quantities.

2.5.2 Haversian Histology Data (Table 7)

Tibial cortical area exhibited no significant differences among C, I, E, and R_5; however, R_{12} increased significantly with respect to each of these quantities. The increase in tibial cortical area may have been the result of normal growth of the animals in the reconditioned group which were not sacrificed until a year after the sacrifice of the animals in the C, I, and E groups and seven months after the R_5 group.

The tibial ratio of cortical to total area also exhibited a clearcut pattern of behavior. Immobilization and exercise of only one leg both caused a significant decrease in this ratio, and the five-month reconditioning period caused no apparent recovery from these depressed levels. The 12-month reconditioning period, however, did effect the recovery to control levels.

Femoral cortical area exhibited the same pattern of significant differences as the tibial cortical area. Thus, immobilization, exercise of only one leg, or reconditioning for five months had no effect upon femoral cortical area, but a 12-month reconditioning period caused a significant increase in the quantity. The femoral ratio of cortical area to total area also exhibited this behavior pattern. Again, this behavior may have reflected nothing more than the extra growth period of the 12-month reconditioned group.

Femoral number of osteoid seams per unit area was decreased by immobilization and exercise of only one leg. Reconditioning, for either five or 12 months, did not bring about recovery of this quantity. Although ER did not show a significant decrease with respect to C while EL did decrease significantly with respect to C, we assumed that exercise of only one leg caused a decrease of the femoral number of osteoid seams per unit area. This was assumed because neither ER nor EL showed significant differences with respect to I, R_5, or R_{12}, each of which decreased significantly with respect to C. The femoral activation frequency also followed this pattern of behavior.

The femoral circumference of osteoid seams exhibited significant decreases from C, I, E, and R_5 to R_{12}. The femoral width of the osteoid seam also exhibited this pattern of significant differences, with the addition of a significant increase from I to E. In any case, immobilization, exercise of only one leg, or five months' reconditioning did not affect the quantity under consideration but after 12 months of reconditioning, significant decreases were apparent. In the case of femoral width

TABLE 7

HAVERSIAN HISTOLOGY DATA*

TIBIA	C vs I	C vs E	C vs R_5	C vs R_{12}	I vs E	I vs R_5	I vs R_{12}	E vs R_5	E vs R_{12}	R_5 vs R_{12}
Ac				**↑			***↑		**↑	***↑
C/T	*↓	*↓	*↓				**↑		*↑	*↑
Af										
Ar										
Sf										
M										
Mf										
μf										
σf										
Ar/Af										
Vf										
W.O.S.										
%										
W.T.										

FEMUR	ER-EL	C vs I	C-ER	C-EL	C vs R_5	C vs R_{12}	I-ER	I-EL	I vs R_5	I vs R_{12}	ER-R_5	EL-R_5	ER-R_{12}	EL-R_{12}	R_5 vs R_{12}
Ac						***↑				***↑			**↑	**↑	*↑
C/T						***↑				***↑			***↑	***↑	***↑
Af		*↓		*↓	*↓	***↓									
Ar						**↓									
Sf						*↓				***↓			*↓	**↓	**↓
M										**↓					*↓
Mf															
μf		*↓		*↓	*↓	**↓									
σf										**↑					*↑
Ar/Af															
Vf				*↓	*↓	**↓									
W.O.S.						***↓	*↑	*↑		**↓			***↓	***↓	**↓
%															

FIBULA	C vs I	C-ER	C-EL	C vs R_4	I-ER	I-EL	I vs R_4	ER vs EL	ER-R_4	EL-R_4
Ac										
C/T	***↓	**↓		*↓						
Af										
Sf			**↑			**↑		*↑		**↓
M										
Mf					*↑					
μf										
σf										
Ar/Af										
Vf										
W.O.S.										
%	***↓				*↑	*↑	**↑			
W.T.										

* Data collected at HFH.

↑increase
↓decrease

of osteoid seams, E was greater than C which was greater than I but neither E nor I was significantly different from C. A similar situation was true for R_5 which lay between E and I and was not significantly different from either.

The femoral bone formation rate did not show a clearcut pattern of significant differences. Although I was not significantly different from C, neither was I significantly different from R_5 nor R_{12}, two quantities which were both significantly lower than C. Furthermore, EL was significantly lower than C, while ER was not. However, all the other comparisons among I, ER, EL, R_5, and R_{12} showed no significant differences. Therefore, that immobilization caused only a slight decrease in femoral bone formation rate was a reasonable assumption. Exercise of only one leg caused a similar decrease. Femoral bone formation rate did not recover upon reconditioning; rather, R_5 and R_{12} showed an even more clearcut decrease from C than did I and E. Perhaps a long lag period exists in the recovery behavior of femoral bone formation rate, so that even after the onset of reconditioning, the rate continues to decrease for at least a short period of time, and recovery is not evident even after 12 months of reconditioning.

Only the percent labeled system showed any clearcut pattern of significant differences in the statistical results for the fibula's haversian histology. That quantity decreased upon immobilization and recovered after four months of reconditioning. Exercise of one leg mitigated the effects of immobilization and maintained fibular percent labeled system at control levels.

2.5.3 Endosteal Histology Data (Table 8)

The statistical results obtained for the endosteal histology of the tibia showed no clearcut pattern of significant differences.

The femur exhibited an extremely odd pattern of significant differences. For eight different quantities, a significant decrease at the 0.005 level existed from C to I and from C to EL. No significant difference existed between C and ER for any of the eight quantities. However, in none of these eight instances did a significant difference exist between ER and EL. Furthermore, the statistical relationships between ER and I, and ER and R_{12} were identical to the corresponding relationships for EL and I and EL and R_{12}.

Five of the eight quantities which exhibited discrepancies in the statistical relationships of ER and EL to C also showed discrepancies in the statistical relationships of ER and EL to R_5. The effect of exercise (or any of the treatments) on any of the femur's endosteal histology quantities, therefore, was impossible to interpret, except for those four

TABLE 8

ENDOSTEAL HISTOLOGY DATA*

TIBIA	C vs I	C vs E	C vs R_5	C vs R_{12}	I vs E	I vs R_5	I vs R_{12}	E vs R_5	E vs R_{12}	R_5 vs R_{12}
P										
Af										
Sf										
W.T.	*↑									
M										
Mf										
σf										
μf										
% labeled sys.						*↑				
% no activity										
% resorption										
% formation										
surface Vf										
M.C.T.							*↑		*↑	
volume Vf										

FEMUR	ER-EL	C vs I	C-ER	C-EL	C vs R_5	C vs R_{12}	I-ER	I-EL	I vs R_5	I vs R_{12}	ER-R_5	EL-R_5	ER-R_{12}	EL-R_{12}	R_5 vs R_{12}
P															
Af															
Sf															
W.T.															
M		***↓		***↓		***↓									*↓
Mf		***↓		***↓		***↓									*↓
σf															
μf		***↓		***↓		***↓									
% labeled sys.		***↓		***↑		*↓			***↑			***↑			
% no activity				***↑								**↓			
% resorption															
% formation		***↓		***↓		*↓			**↑			***↑			
surface Vf		***↓		***↓		***↓			**↑			**↑			*↓
M.C.T.		***↑								***↑			***↑	***↑	*↑
volume Vf		***↓		***↓		*** ↓			*↑			*↑			*↓

FIBULA	C vs I	C-ER	C-EL	C vs R_4	I-ER	I-EL	I vs R_4	ER vs EL	ER-R_4	EL-R_4
P	***↑	*↑		*↑						
Af										
Sf										
W.T.									*↑	
M		**↑		**↑	***↑		**↑			
Mf		**↑		**↑	***↑		**↑			
σf										
μf					*↑					
% labelled sys.										
% no activity										
% resorption										
% formation										
surface Vf		**↑		*↑	**↑		**↑	*↓		*↑
M.C.T.										
volume Vf		**↑			***↑		**↑	**↓	*↓	

* Data collected at HFH.

quantities showing no significant differences from treatment to treatment.

A similar confusing situation involving ER and EL existed for the fibula's statistical results. A meaningful interpretation of these results was therefore practically impossible.

2.6 LINEAR REGRESSION ANALYSIS OF FRACTURED BONE DATA

2.6.1 Variables Plotted Against Maximum Load (Table 9)

The quantities of volume, dry weight, and ash weight correlated strongly with maximum load for the control specimens of each bone tested. Immobilization caused these correlations to be lost entirely for the tibia but did not affect them for the humerus. The femur retained the correlations between maximum load and both dry weight and ash weight after immobilization but lost the correlation between maximum load and volume. Exercise of one leg caused these three correlations to be lost in all three bones, although the tibia-exercised left specimens retained the correlations between maximum load and both dry and ash weight. Five months of reconditioning caused all three bones to regain each of these three correlations.

Another noteworthy set of correlations occurred between maximum load and percent ash for the control specimens of each bone tested. Immobilization caused these correlations to be lost and exercise of one leg did not reverse the situation. Moreover, these correlations were not regained after five months of reconditioning.

2.6.2 Variables Plotted Against Rotation to Fail (Table 10)

The density and ash content correlated significantly with rotation to failure for the control specimens of the femur. The correlations did not occur between these two quantities and rotation to failure for the immobilized femur specimens or the exercised femur specimens. After a five-month reconditioning period, both correlations reappeared. This pattern of loss of correlation upon immobilization or exercise of only one leg with recovery of correlation upon reconditioning was seen nowhere else in this portion of the linear regression analysis.

Percent ash showed a significant correlation with rotation to fail for the reconditioned specimens of all three bones tested.

2.6.3 Variables Plotted Against Energy to Fail (Table 11)

Both the tibia and humerus showed correlations between energy to failure and the quantities of volume, dry weight, and ash weight for their control specimens. These

TABLE 9

LINEAR REGRESSION: VARIABLES PLOTTED AGAINST MAXIMUM LOAD

vs.	R	T	vs.	R	T	vs.	R	T
Tibia - Control			**Femur - Control**			**Humerus - Control**		
ML VOL	0.78	***	ML VOL	0.80	***	ML VOL	0.78	***
ML DrWt	0.79	***	ML DrWt	0.83	***	ML DrWt	0.81	***
ML A Wt	0.81	***	ML A Wt	0.87	***	ML A Wt	0.84	***
ML Dens	-0.15	---	ML Dens	-0.26	---	ML Dens	-0.30	---
ML A Con	-0.04	---	ML A Con	-0.12	---	ML A Con	-0.09	---
ML % A	0.53	**	ML % A	0.77	***	ML % A	0.69	***
ML Cap	0.10	0.47	ML Cap	0.04	0.21	ML Cap	0.06	0.28
ML PrWt	0.21	0.98	ML PrWt	0.23	1.13	ML PrWt	0.22	1.06
Tibia - Immobilized			**Femur - Immobilized**			**Humerus - Immobilized**		
ML VOL	0.33	1.41	ML VOL	0.49	2.04	ML VOL	0.66	**
ML DrWt	0.40	1.72	ML DrWt	0.64	*	ML DrWt	0.79	***
ML A Wt	0.38	0.66	ML A Wt	0.65	**	ML A Wt	0.75	**
ML A Con	0.07	0.29	ML Dens	0.24	0.89	ML Dens	0.21	0.78
ML % A	0.02	0.09	ML A Con	0.28	1.04	ML A Con	0.12	0.43
ML Cap	0.07	0.28	ML % A	0.31	1.19	ML % A	-0.43	---
ML PrWt	0.40	1.78	ML Cap	0.38	1.57	ML Cap	-0.05	---
ML PstWt	0.59	*	ML PrWt	0.47	2.05	ML PrWt	0.38	1.47
			ML PstWt	0.12	0.38	ML PstWt	0.28	0.84
Tibia - Ex. Right			**Femur - Ex. Right**			**Humerus - Exercised**		
ML VOL	0.56	1.96	ML VOL	0.41	1.35	ML VOL	0.02	0.08
ML DrWt	0.56	1.02	ML DrWt	0.48	1.63	ML DrWt	0.48	1.95
ML A Wt	0.50	1.64	ML A Wt	0.55	1.95	ML A Wt	0.46	1.86
ML Dens	0.12	0.33	ML Dens	0.02	0.05	ML Dens	0.45	1.84
ML A Con	-0.13	---	ML A Con	0.19	0.59	ML A Con	0.46	1.89
ML % A	-0.14	---	ML % A	0.49	1.71	ML Cap	0.08	0.27
ML Cap	-0.37	---	ML Cap	0.02	0.06	ML % A	0.10	0.36
ML PrWt	0.37	1.14	ML PrWt	0.38	1.23	ML PrWt	-0.29	---
ML PstWt	0.43	1.26	ML PstWt	0.23	0.65	ML PstWt	-0.19	---

R = correlation coefficient, T = t statistic for R to test for a significant difference from R = 0.

TABLE 9 (concluded)

LINEAR REGRESSION: VARIABLES PLOTTED AGAINST MAXIMUM LOAD

vs.	R	T	vs.	R	T	vs.	R	T
Tibia - Ex. Left			Femur - Ex. Left					
ML VOL	0.52	1.48	ML VOL	0.56	1.77			
ML DrWt	0.75	*	ML DrWt	0.52	1.60			
ML A Wt	0.80	*	ML A Wt	0.47	1.42			
ML Dens	0.52	1.48	ML A Con	-0.40	---			
ML A Con	0.60	1.83	ML Dens	-0.44	---			
ML % A	0.52	1.50	ML % A	-0.15	---			
ML Cap	0.08	0.19	ML Cap	0.28	0.84			
ML PrWt	0.29	0.75	ML PrWt	-0.37	---			
ML PstWt	0.10	0.23	ML PstWt	-0.36	---			
Tibia - Recond. 5 mo.			Femur - Recond. 5 mo.			Humerus - Recond. 5 mo.		
ML VOL	0.77	***	ML VOL	0.66	***	ML VOL	0.50	*
ML DrWt	0.84	***	ML DrWt	0.69	***	ML DrWt	0.51	*
ML A Wt	0.84	***	ML A Wt	0.71	***	ML A Wt	0.52	*
ML Dens	0.21	0.97	ML Dens	0.07	0.30	ML Dens	-0.08	---
ML % A	0.33	1.56	ML A Con	0.17	0.77	ML A Con	0.09	0.38
ML Cap	-0.43	*	ML % A	0.50	*	ML % A	0.32	1.48
ML PrWt	0.55	**	ML Cap	-0.35	---	ML Cap	-0.22	---
ML PstWt	0.70	***	ML PrWt	0.62	**	ML PrWt	0.43	*
ML RecWt	0.87	***	ML PstWt	0.67	***	ML PstWt	0.28	1.26
ML A Con	0.26	1.22	ML RecWt	0.56	2.13	ML RecWt	0.26	0.87

R = correlation coefficient, T = t statistic for R to test for a significant difference from R = 0.

TABLE 10

LINEAR REGRESSION: VARIABLES PLOTTED AGAINST ROTATION TO FAIL

vs.	R	T	vs.	R	T	vs.	R	T
Tibia - Control			**Femur - Control**			**Humerus - Control**		
RF VOL	0.09	0.43	RF VOL	-0.40	*	RF VOL	-0.05	---
RF DrWt	0.10	0.48	RF DrWt	-0.27	---	RF DrWt	0.06	0.30
RF A Wt	0.07	0.34	RF A Wt	-0.26	---	RF A Wt	0.03	0.13
RF Dens	-0.06	---	RF Dens	0.48	*	RF Dens	0.30	1.48
RF A Con	-0.14	---	RF A Con	0.46	*	RF A Con	0.22	1.08
RF % A	-0.35	---	RF % A	-0.10	---	RF % A	-0.27	---
Tibia - Immobilized			**Femur - Immobilized**			**Humerus - Immobilized**		
RF VOL	-0.49	*	RF VOL	-0.23	---	RF VOL	-0.08	---
RF DrWt	-0.32	---	RF DrWt	-0.37	---	RF DrWt	-0.10	---
RF A Wt	-0.32	---	RF A Wt	-0.38	---	RF A Wt	-0.13	---
RF Dens	0.54	*	RF Dens	-0.27	---	RF Dens	-0.09	---
RF A Con	0.48	*	RF A Con	-0.28	1.07	RF A Con	-0.29	---
RF % A	-0.25	---	RF % A	-0.21	---	RF % A	-0.53	*
Tibia - Ex. Right			**Femur - Ex. Right**			**Humerus - Exercised**		
RF VOL	-0.15	---	RF VOL	-0.10	---	RF VOL	-0.07	---
RF DrWt	-0.38	---	RF DrWt	-0.24	---	RF DrWt	-0.10	---
RF A Wt	-0.47	---	RF A Wt	-0.29	---	RF A Wt	-0.15	---
RF Dens	-0.31	---	RF Dens	-0.29	---	RF Dens	-0.00	---
RF A Con	-0.40	---	RF A Con	-0.34	---	RF A Con	-0.06	---
RF % A	-0.78	**	RF % A	-0.36	---	RF % A	-0.27	---
Tibia - Ex. Left			**Femur - Ex. Left**					
RF VOL	0.48	1.35	RF VOL	0.45	1.33			
RF DrWt	0.47	1.29	RF DrWt	0.26	0.71			
RF A Wt	0.42	1.13	RF A Wt	0.17	0.47			
RF Dens	0.11	0.27	RF Dens	-0.71	*			
RF A Con	0.08	0.21	RF A Con	-0.79	*			
RF % A	-0.23	---	RF % A	-0.50	---			
Tibia - Recond. 5 mo.			**Femur - Recond. 5 mo.**			**Humerus - Recond. 5 mo.**		
RF VOL	0.10	0.43	RF VOL	-0.42	---	RF VOL	-0.37	---
RF DrWt	0.08	0.36	RF DrWt	-0.53	*	RF DrWt	-0.41	---
RF A Wt	0.04	0.19	RF A Wt	-0.56	**	RF A Wt	-0.46	*
RF Dens	-0.05	---	RF Dens	-0.43	*	RF Dens	-0.24	---
RF A Con	-0.14	---	RF A Con	-0.49	*	RF A Con	-0.44	*
RF % A	-0.50	*	RF % A	-0.55	**	RF % A	-0.71	***

R = correlation coefficient, T = t statistic to test for a significant difference from R = 0.

TABLE 11

LINEAR REGRESSION: VARIABLES PLOTTED AGAINST ENERGY TO FAIL

vs.	R	T	vs.	R	T	vs.	R	T
Tibia - Control			**Femur - Control**			**Humerus - Control**		
EF VOL	0.46	*	EF VOL	0.13	0.62	EF VOL	0.43	*
EF DrWt	0.48	*	EF DrWt	0.27	1.34	EF DrWt	0.55	**
EF A Wt	0.47	*	EF A Wt	0.30	1.48	EF A Wt	0.53	**
EF Dens	-0.12	---	EF Dens	0.27	1.33	EF Dens	0.09	0.42
EF A Con	-0.12	---	EF A Con	0.35	1.73	EF A Con	0.14	0.66
EF % A	0.05	0.25	EF % A	0.42	2.20	EF % A	0.11	0.51
Tibia - Immobilized			**Femur - Immobilized**			**Humerus - Immobilized**		
EF VOL	-0.01	---	EF VOL	0.08	0.29	EF VOL	0.51	2.13
EF DrWt	-0.22	---	EF DrWt	0.04	0.15	EF DrWt	0.51	2.15
EF A Wt	0.20	0.83	EF A Wt	-0.38	---	EF A Wt	0.47	1.92
EF Dens	0.55	*	EF Dens	-0.27	---	EF Dens	0.15	0.54
EF A Con	0.52	*	EF A Con	-0.28	---	EF A Con	-0.10	0.35
EF % A	-0.06	---	EF % A	-0.21	---	EF % A	-0.52	*
Tibia - Ex. Right			**Femur - Ex. Right**			**Humerus - Exercised**		
EF VOL	-0.02	---	EF VOL	0.21	0.64	EF VOL	-0.07	---
EF DrWt	-0.27	---	EF DrWt	0.15	0.47	EF DrWt	0.19	0.68
EF A Wt	-0.35	---	EF A Wt	0.15	0.44	EF A Wt	0.15	0.54
EF Dens	-0.33	---	EF Dens	-0.20	---	EF Dens	0.30	1.09
EF A Con	-0.41	---	EF A Con	-0.16	---	EF A Con	0.24	0.91
EF % A	-0.64	*	EF % A	-0.03	---	EF % A	-0.13	---
Tibia - Ex. Left			**Femur - Ex. Left**					
EF VOL	0.49	1.37	EF VOL	0.52	1.62			
EF DrWt	0.64	2.02	EF DrWt	0.37	1.04			
EF A Wt	0.64	2.02	EF A Wt	0.31	0.86			
EF Dens	0.38	1.01	EF Dens	-0.68	*			
EF A Con	0.40	1.08	EF A Con	-0.67	*			
EF % A	0.13	0.33	EF % A	-0.26	---			
Tibia - Recond. 5 mo.			**Femur - Recond. 5 mo.**			**Humerus - Recond. 5 mo.**		
EF VOL	0.48	*	EF VOL	0.01	0.04	EF VOL	-0.08	---
EF DrWt	0.50	*	EF DrWt	-0.08	---	EF DrWt	-0.13	---
EF A Wt	0.48	*	EF A Wt	-0.10	---	EF A Wt	-0.16	---
EF Dens	0.05	0.22	EF Dens	-0.36	---	EF Dens	-0.29	---
EF A Con	0.02	0.08	EF A Con	-0.35	---	EF A Con	-0.38	---
EF % A	-0.14	---	EF % A	-0.21	---	EF % A	-0.45	*

R = correlation coefficient, T = t statistic for R to test for a significant difference from R = 0.

correlations were lost upon immobilization. Exercise of only one leg did not prevent this loss of correlation. After five months of reconditioning, the tibia had regained these correlations; the humerus had not.

2.7 STEROID STUDY

Adult male rhesus monkeys were divided into experimental groups and an untreated control group. The experimental groups were injected according to varying patterns of dosage and frequency. Steroids were injected into the right knee, and an equal volume of normal saline was injected into the left knee (sham treatment). After completion of the experimental period, the animals were sacrificed by phenobarbital overdose. Both femur-knee-tibia units were removed intact from each animal. The excess flesh was removed from each unit and the knee capsule and ligaments were carefully cut away so that only the anterior cruciate ligament remained joining the femur to the tibia. These preparations were tested to failure under tension. Oscillographic load-extension recordings were made of each test, and various mechanical parameters were obtained from them. (For the details concerning data collection see IMMOBILIZATION STUDY, PROCEDURE, DATA COLLECTION.)

The relationship between the variables load and extension was studied. There were three test groups of monkeys: a control group and two groups receiving the steroid/sham treatment described above, making a total of five data groups, a control group, two steroid groups (S12 and S13), and two sham groups (O12 and O13). The data for each ligament in each data group were analyzed. The least squares fits of linear, quadratic, and cubic polynomials were compared using an F-Statistic to determine the significance of the error in the fit. A cubic polynomial was needed to give an adequate fit to the data for each individual ligament due to the curvature observed in the data for load versus extension. A cubic equation was then fit by the method of least squares for the combined data within each of the five data groups. Statistical tests were used to determine if any of the groups could be combined. The statistical procedure consisted of fitting a cubic equation to two groups separately and then combining the data from the two groups and fitting a cubic equation to the combined data. The error or lack of fit in the three equations was then compared by means of an F-statistic. A large F-statistic indicated that the data for the two groups did not fit the same equation. If the F-statistic was close to 1, combining the data from the two groups was done.

An example of this procedure is detailed in Figures 3, 4, and 5. Figure 3 shows load vs. extension plots for individual steroid-injected knees. Figure 4 shows load vs. extension plots for individual sham-injected knees. Figure 5 shows the composite

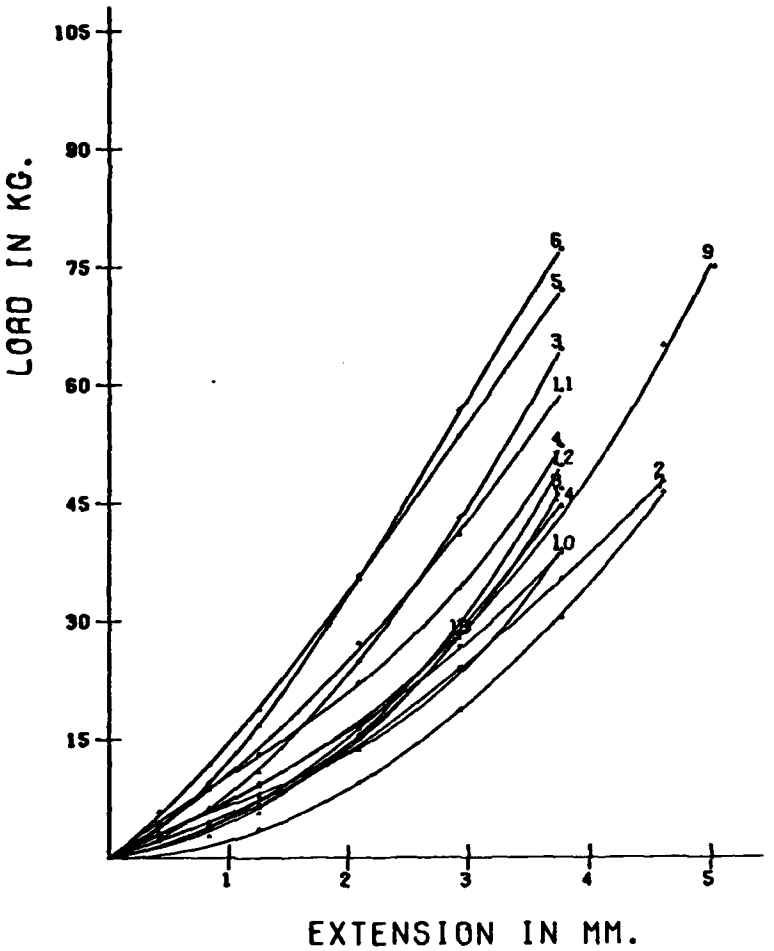


Figure 3. Load vs. Extension Plots for Individual Steroid-Injected Knees.

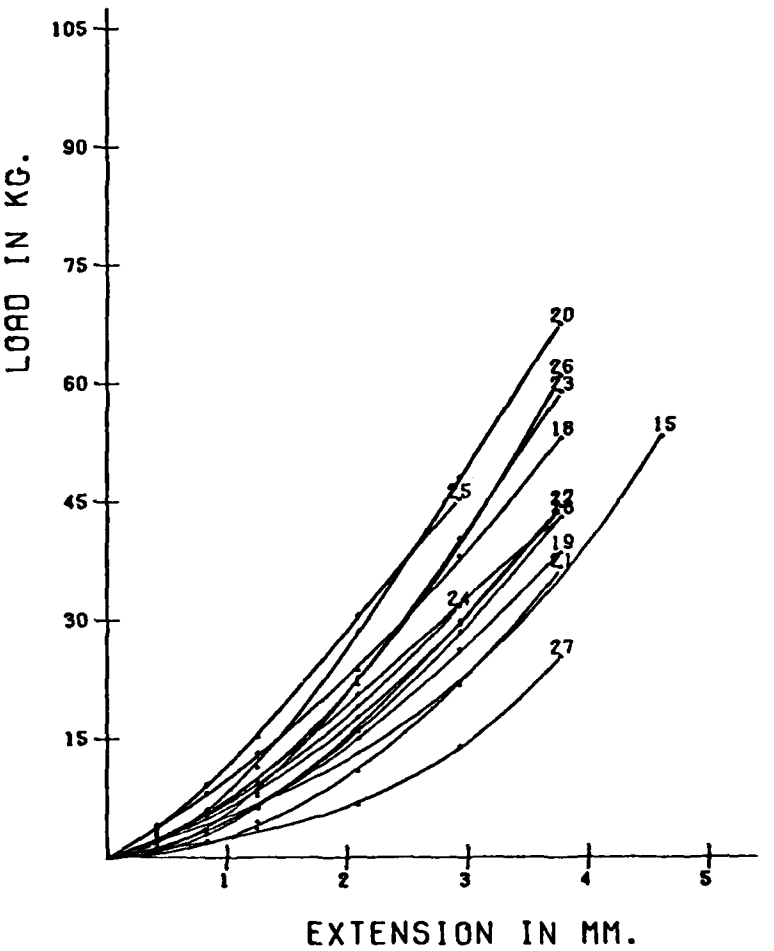


Figure 4. Load vs. Extension Plots for Individual Sham-Injected Knees.

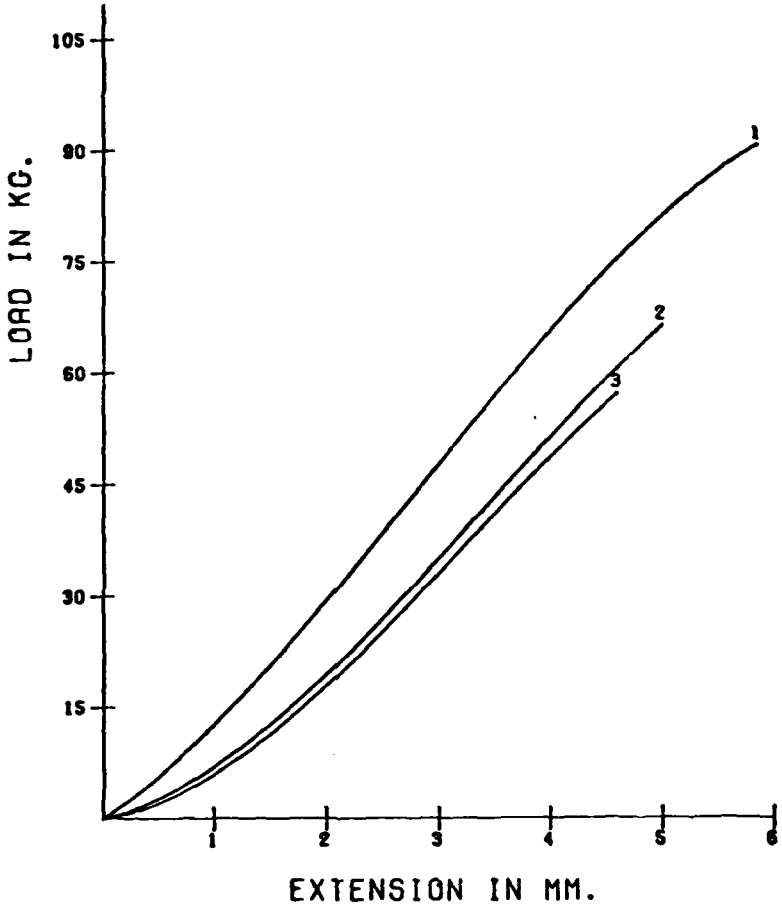


Figure 5. Comparison of Composite Curves for the Control Group (Curve 1), the Steroid-Injected Knees (Curve 2), and the Sham-Injected Group (Curve 3).

curve for the control group (curve 1) compared with the composite curves for the steroid group (curve 2) and the sham group (curve 3).

For a more complete discussion of the computer programs used in this analysis, see Appendix D.

SECTION 3
CONCLUSIONS

3.1 FRACTURED BONES, TORSION

In every case, immobilization and/or exercise of only one leg caused decreases in ML, MLL, and EMLL. Other torsional properties also showed decreasing trends for these treatments.

Reconditioning for five months effected recovery of ML and MLL and might have effected recovery of other properties had a period longer than five months been employed.

3.2 FRACTURED BONES, ASH

Immobilization and/or exercise of only one leg caused decreases in dry weight and ash weight for all three bones tested. These treatments caused decreases in volume for the femur and the humerus, but not for the tibia.

Reconditioning for five months effected recovery of volume, dry weight, and ash weight of the humerus. The five-month reconditioning period did not effect recovery of these quantities for the tibia or femur.

Volume, dry weight, and ash weight were lost at about the same rate within each bone during immobilization. The recovery rates during reconditioning were nearly the same within each bone but varied between bones.

3.3 FRACTURED BONES, CHEMICAL

Calcium, magnesium, and phosphorus content of all three bones tested decreased with immobilization at approximately the same rate as volume and dry weight.

Exercise of only one leg exacerbated the decline in humerus calcium weight.

3.4 WHOLE BONES, ASH AND CHEMICAL

Immobilization and reconditioning caused no significant effects upon the ash and chemical quantities measured for the

radius, fibula, and ulna. Minor changes occurred in tibial levels of phosphorus, magnesium, and calcium.

The femur showed a significant loss of dry and ash weight during immobilization with recovery upon reconditioning.

The humerus showed no significant decrease in dry weight, ash weight, or percent ash during immobilization, but these quantities all increased upon reconditioning (due, perhaps, to normal growth).

The chemical data for both the femur and the humerus showed no significant differences from treatment to treatment. The changes observed in dry and ash weight observed in these two bones were small.

3.5 SMALL BONES, ASH AND CHEMICAL

Talus volume decreased upon immobilization. Exercise of only one leg mitigated this decrease. Talus volume began to recover soon after the initiation of reconditioning and continued to recover gradually. Talus dry and ash weight decreased upon immobilization and/or exercise of only one leg. These quantities did not begin to recover until sometime after the fifth month of reconditioning, but then recovery was rapid. Calcaneus volume, dry weight, and ash weight behaved similarly to talus volume, dry weight, and ash weight. The behavior of the calcium, phosphorus, and magnesium weights closely paralleled dry and ash weight for both the talus and the calcaneus.

3.6 HISTOLOGY DATA (PERIOSTEAL)

Tibial circumference of osteoid seams and tibial percent formation were not affected by immobilization or exercise of only one leg; however, both quantities increased significantly upon reconditioning. Tibial percent formation increased more rapidly upon reconditioning than did tibial circumference.

Tibial mean cortical thickness was decreased significantly by immobilization and/or exercise of only one leg. Reconditioning for 12 months effected recovery.

The number of femoral osteoid seams per unit area was not affected by immobilization or exercise of only one leg; however, reconditioning for 12 months caused a significant decrease in this quantity.

Femoral mean appositional rate and femoral radial closure rate both decreased upon immobilization and recovered to control levels after five months of reconditioning.

Femoral percent resorption was decreased after 12 months of reconditioning.

Femoral mean cortical thickness was increased by 12 months of reconditioning although it was not decreased by immobilization and/or exercise of only one leg.

Fibular mean appositional rate, radial closure rate, and surface based bone formation rate followed the simple pattern of decrease upon immobilization with recovery upon reconditioning. Exercise of only one leg did not affect these quantities; i.e., exercise of only one leg mitigated the effect of immobilization on these quantities.

3.7 HISTOLOGY DATA (HAVERSIAN)

Tibial cortical area increased after 12 months of reconditioning. Immobilization, exercise of only one leg, and five months of reconditioning had no effect upon tibial cortical area.

The tibial ratio of cortical area to total area was decreased by both immobilization and exercise of only one leg. Five months of reconditioning did not effect the recovery of this ratio; however, 12 months of reconditioning did effect recovery.

Femoral cortical area and the femoral ratio of cortical area to total area was not affected by immobilization, exercise of only one leg, and reconditioning for five months. Twelve months of reconditioning caused these parameters to increase.

The femoral number of osteoid seams per unit area and the femoral activation frequency was decreased by immobilization and did not recover after 12 months of reconditioning.

The femoral circumference of osteoid seams and the femoral width of osteoid seams were not affected by immobilization, exercise of only one leg, and five months of reconditioning. Twelve months of reconditioning caused significant decreases in these quantities.

Fibular percent labeled system decreased upon immobilization and recovered after four months of reconditioning. Exercise of only one leg mitigated the effects of immobilization.

3.8 LINEAR REGRESSION ANALYSIS OF FRACTURED BONE DATA

The quantities of volume, dry weight, and ash weight all correlated strongly with maximum load for the control specimens of all three bones tested (tibia, femur, humerus). Immobilization caused the tibia to lose these correlations and the femur to lose only the correlation between volume and maximum load. The humerus retained all its correlations upon immobilization. Five months of reconditioning caused these correlations to be regained.

The quantities of density and ash content correlated significantly with rotation to failure for the control specimens of the femur. Immobilization and/or exercise of one leg caused these correlations to be lost. The correlations were regained after five months of reconditioning.

The quantities of volume, dry weight, and ash weight all correlated strongly with the control specimens of the tibia and the humerus. These correlations were lost upon immobilization. After five months of reconditioning, the tibia had regained these correlations; the humerus had not.

APPENDIX A

BMD DISCUSSION

The BMD series was developed by the University of California, Los Angeles, Health Science Computing Facility. This group of programs is used in a wide range of instances in biomedical data analysis. In this project, three of the BMD programs were used.

BMDO2R

This program performs a step-wise regression in fitting an equation to a given set of data. The equation can be "forced" to be a quadratic, cubic, etc., or the BMD can be allowed to find the best possible equation.

BMDO1V

This program provides an analysis of variance table for a single variable of unequal groups. The F-statistic was generally the only value used from this output.

BMDO3D

This program offers a correlation matrix for up to 90 variables. It was used as a general reference throughout the entire project to detect a trend in relationships of differing test parameters.

APPENDIX B

ANALYSIS OF VARIANCE SERIES DISCUSSION

A series of programs was developed to perform an analysis of variance. This series was used extensively in the entire project. The results were used only as a beginning in the analysis

because the test is not very sensitive but it does demonstrate major significant differences.

(1) The program "COP" was run on the original data. This program transforms the data into single-parameter data items. For example, the ash data consisted of six parameters, but the BMD01V (see Appendix A) examined each parameter separately, so COP, in effect, generated six decks of single-parameter data. The output from COP was then ready to be input into the BMD01V.

(2) The BMD01V provided an F-statistic which indicated any significant differences in the groups tested. If the F-statistic was insignificant, the study was completed.

(3) "RANGE" was written to perform a Duncan Range Test on the BMD01V output. If the F-statistic was insignificant, the value was merely reported. A significant F-statistic resulted in a Range Test.

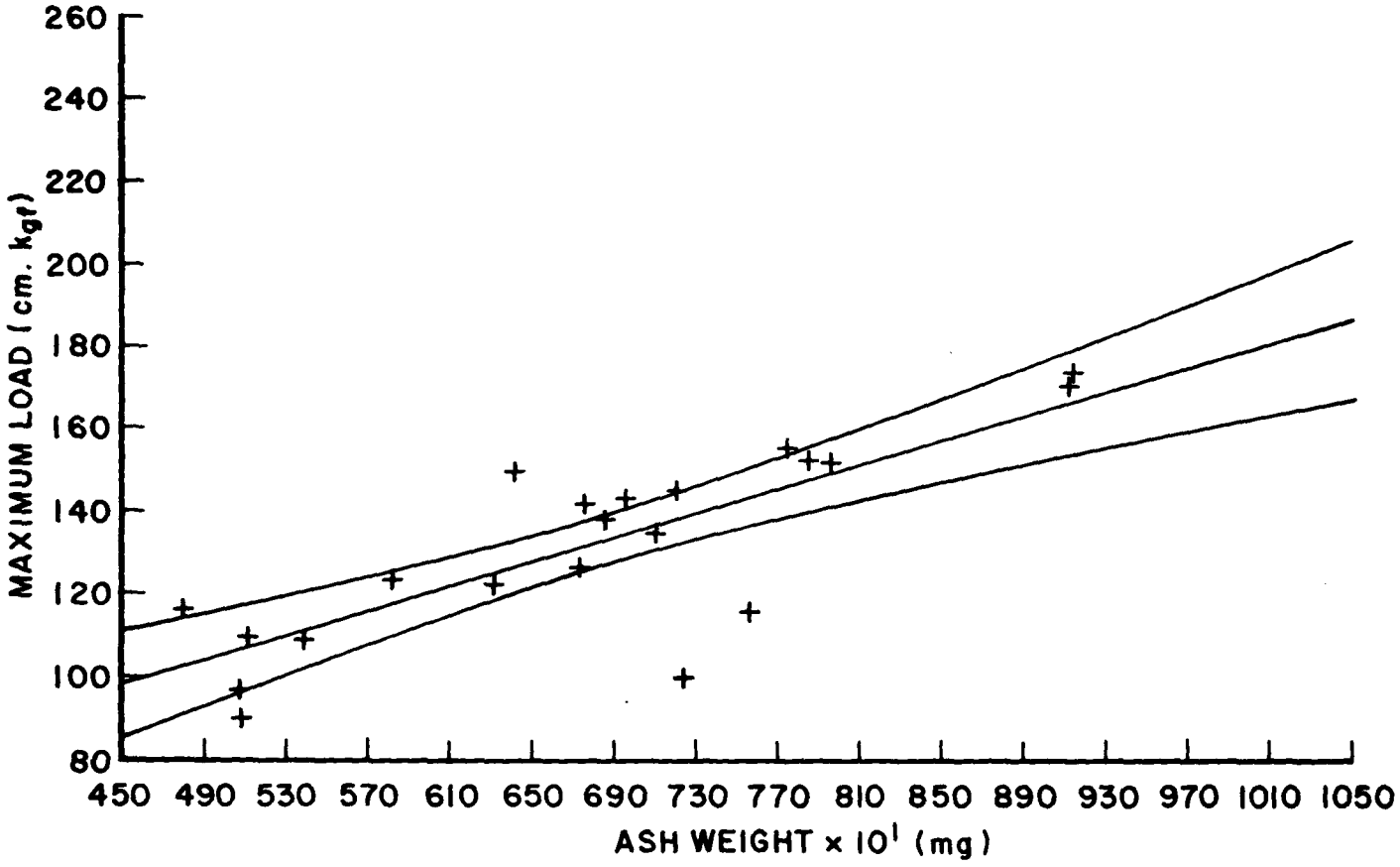
APPENDIX C

SCATTER PLOTS

A program was devised to generate scatter plots (see Figures 6 through 19) on an off-line plotter. The x and y coordinates were read and processed. The processing included the derivation of many parameters used in determining the correlation between x and y. The following values were computed for each scatter plot:

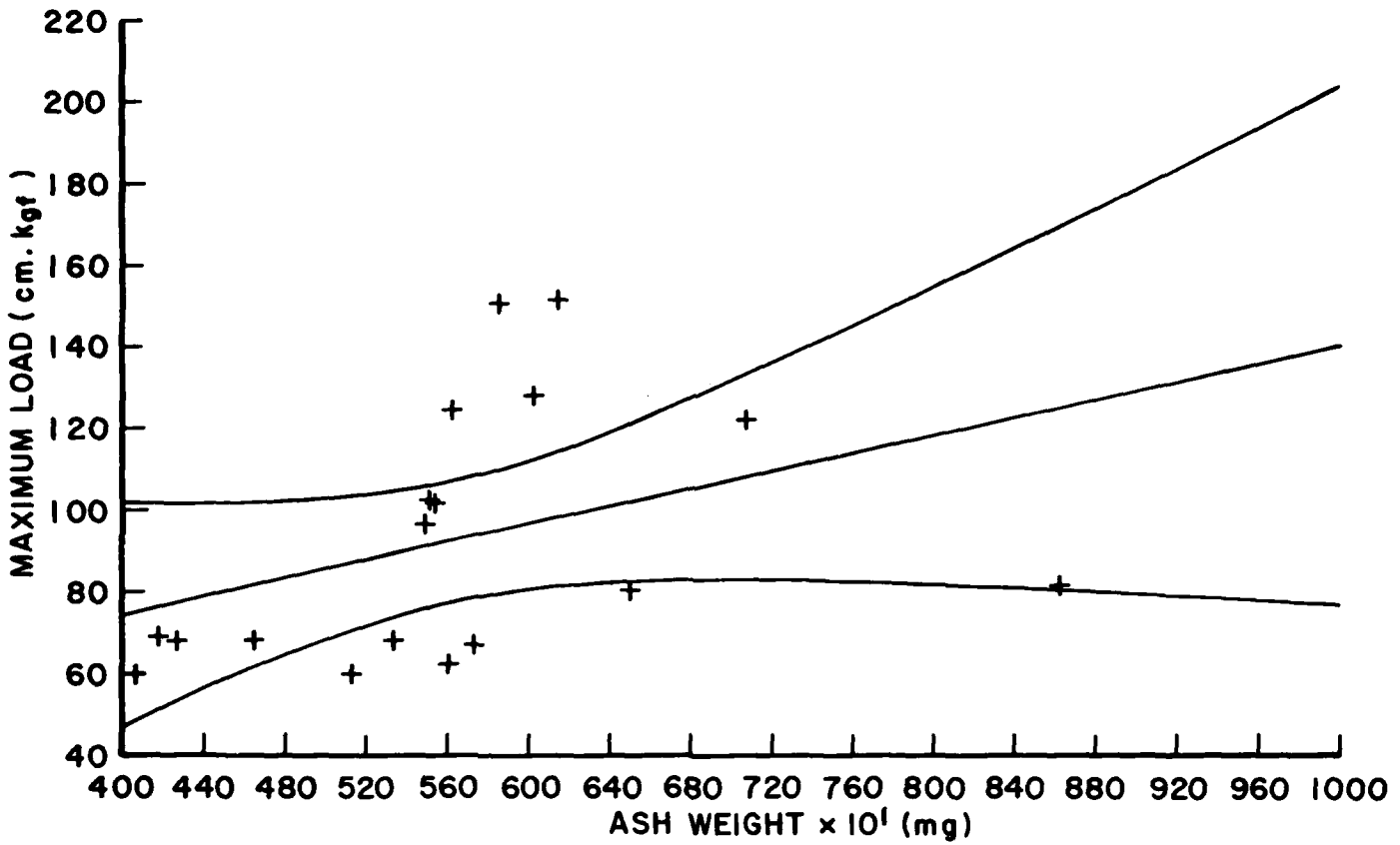
- x intercept (x_o)
- y intercept (y_o)
- mean of x ($\bar{x}$)
- standard deviation of x (σ_x)
- mean of y ($\bar{y}$)
- standard deviation of y (σ_y)
- correlation coefficient (R)
- t-statistic (t). This statistic determines if R is significantly different from zero. Significant differences are indicated by asterisks; * = significance at the 0.05 level, ** = significance at the 0.01 level, *** = significance at the 0.005 level.
- standard error of the regression (SE)
- 95% confidence bands (The means of the data should fall within the two bands 95% of the time.)

The plot itself consisted of plots of the individual data points, the linear regression line, and confidence bands. In the margin below the x-axis, the number of data points (n) and the other values (listed above) were reported.



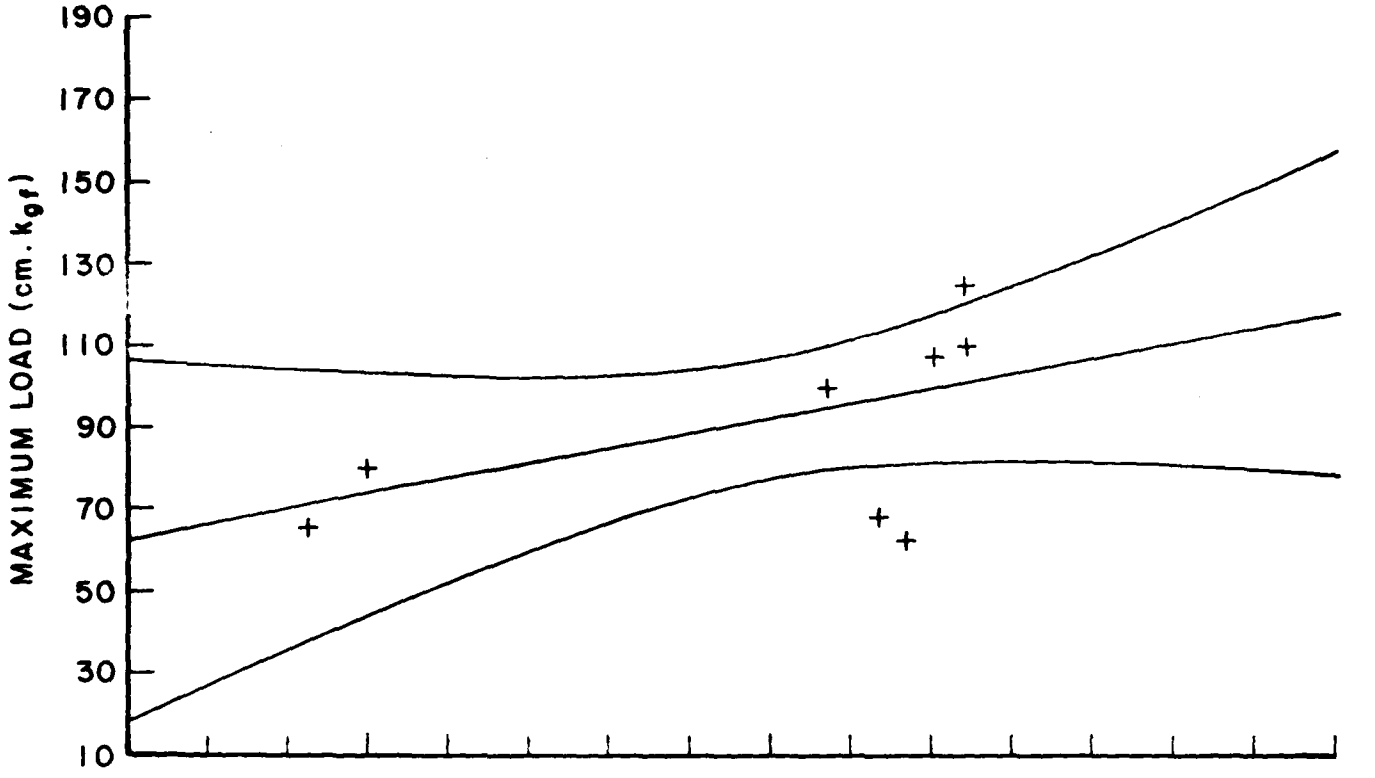
n = 23	$\bar{x}$ = 6770.739	$\bar{y}$ = 131.923	R = 0.8050
x_0 = 31.4672	σ_x = ± 1229.509	σ_y = ±22.660	t = 6.2182***
y_0 = 0.0148			SE = 13.7599

Figure 6. Tibia, Control.



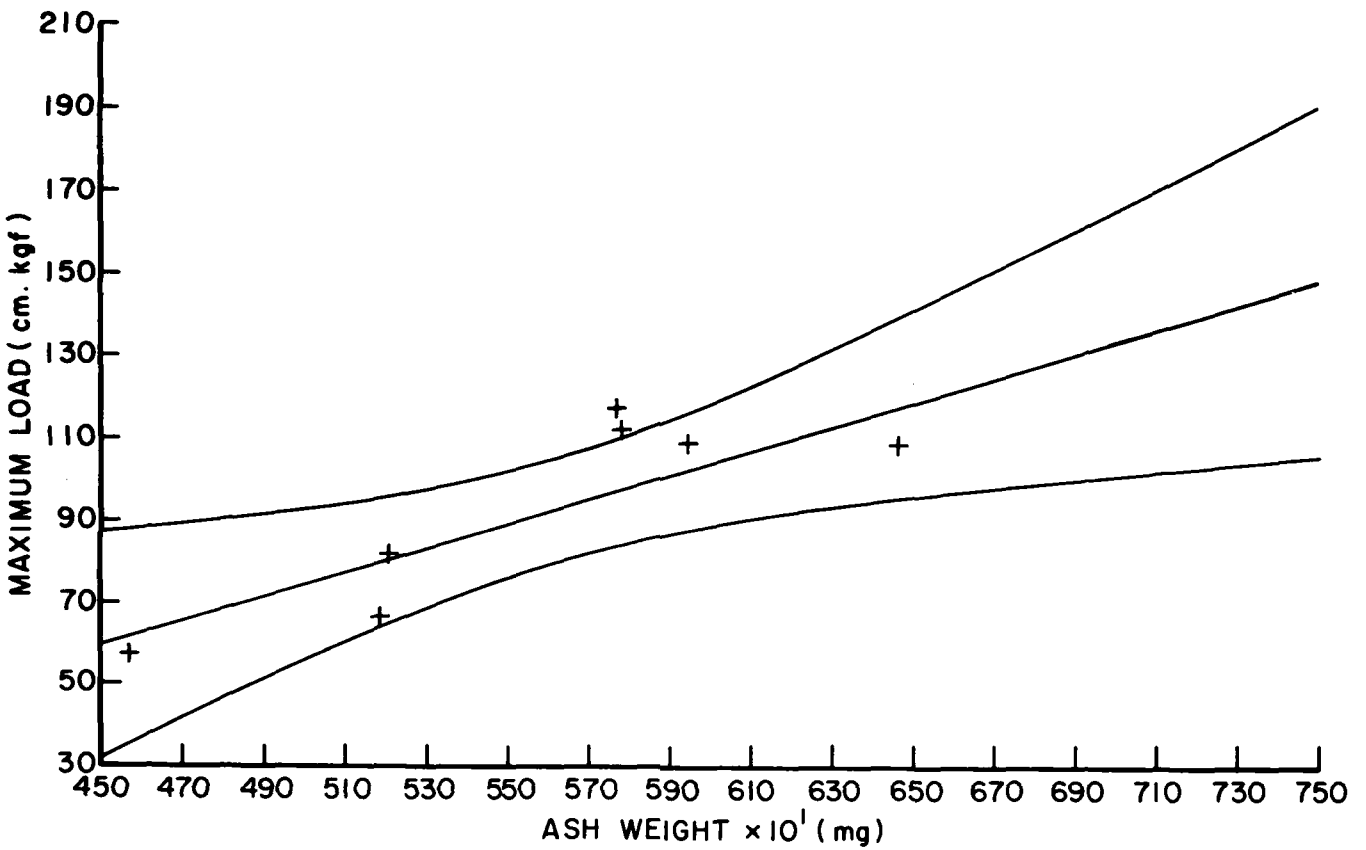
n = 18	$\bar{x}$ = 5638.000	$\bar{y}$ = 92.529	R = 0.3826
x_0 = 30.4778	σ_x = ±1087.120	σ_y = ±31.271	t = 1.6565
y_0 = 0.0110			SE= 29.7805

Figure 7. Tibia, Immobilized.



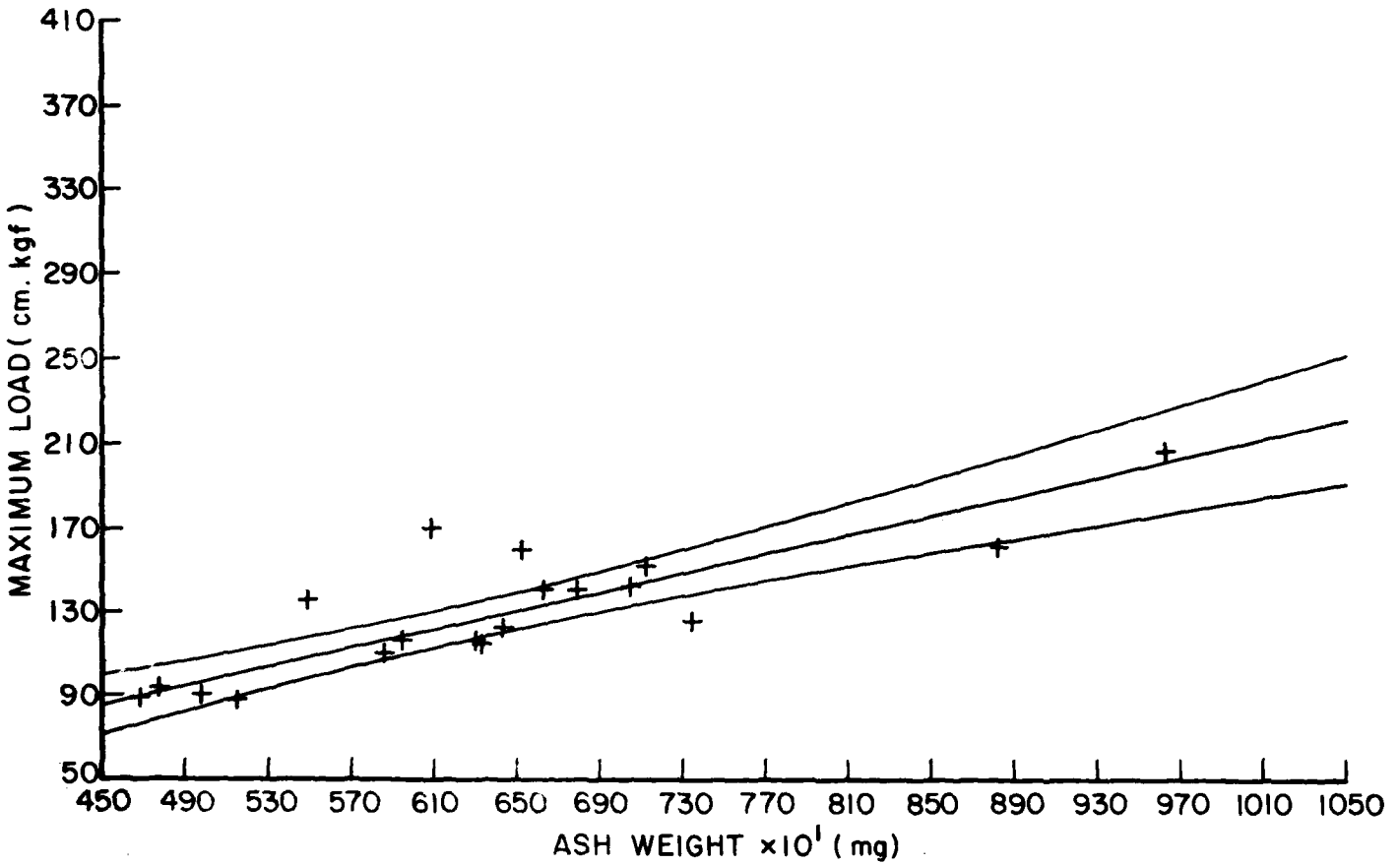
n = 10	$\bar{x}$ = 5592.400	$\bar{y}$ = 91.981	R = 0.5007
x_0 = −11.7967	σ_x = ±593.544	σ_y = ±21.997	t = 1.6351
y = 0.0186			SE= 20.1950

Figure 8. Tibia, Exercised Right.



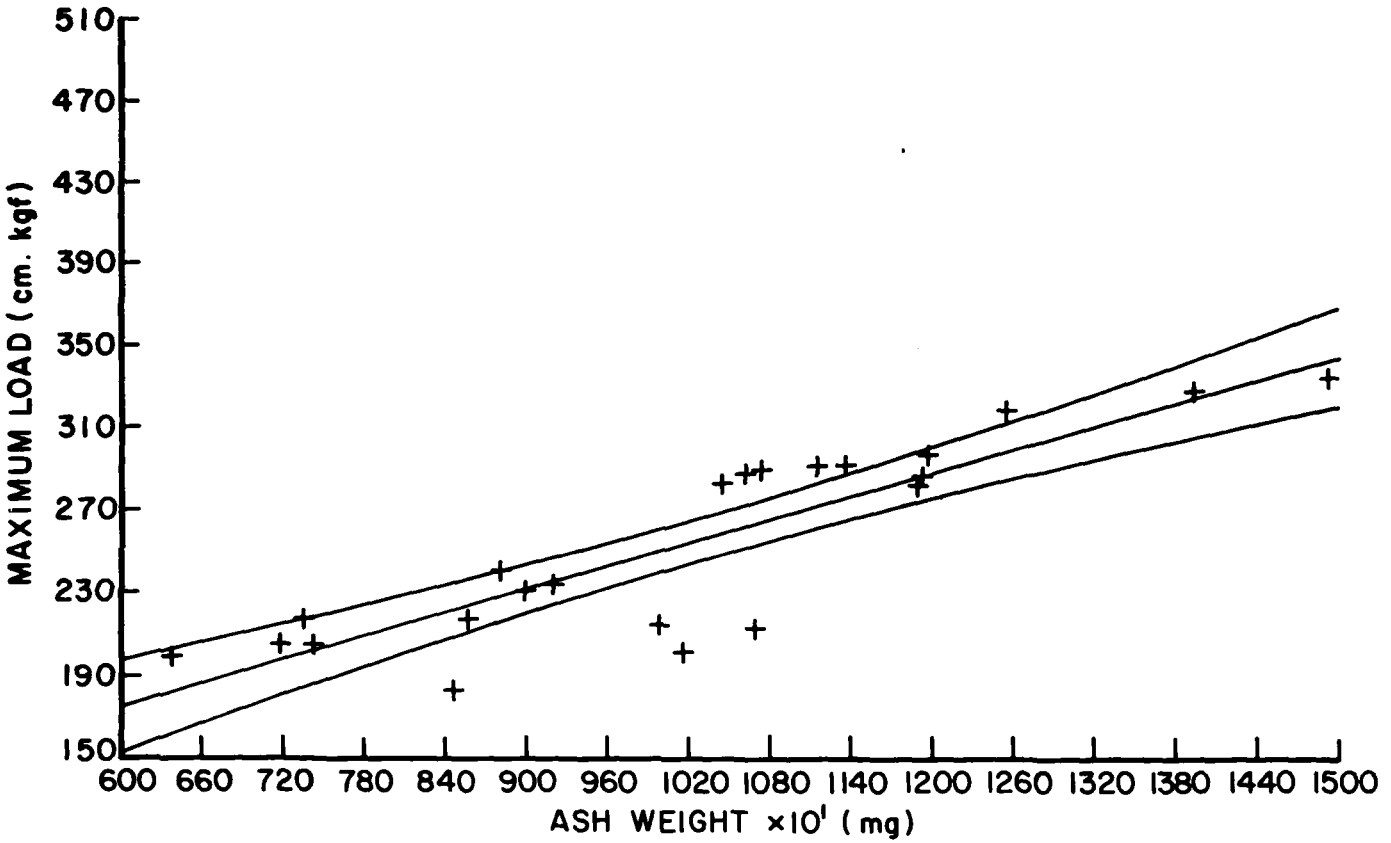
n = 8	$\bar{x}$ = 5641.000	$\bar{y}$ = 93.144	R = 0.8016
x_0 = -71.7323	σ_x = ± 614.828	σ_y ±22.418	t = 3.2842 *
y_0 = 0.0292			SE = 14.4770

Figure 9. Tibia, Exercised Left.



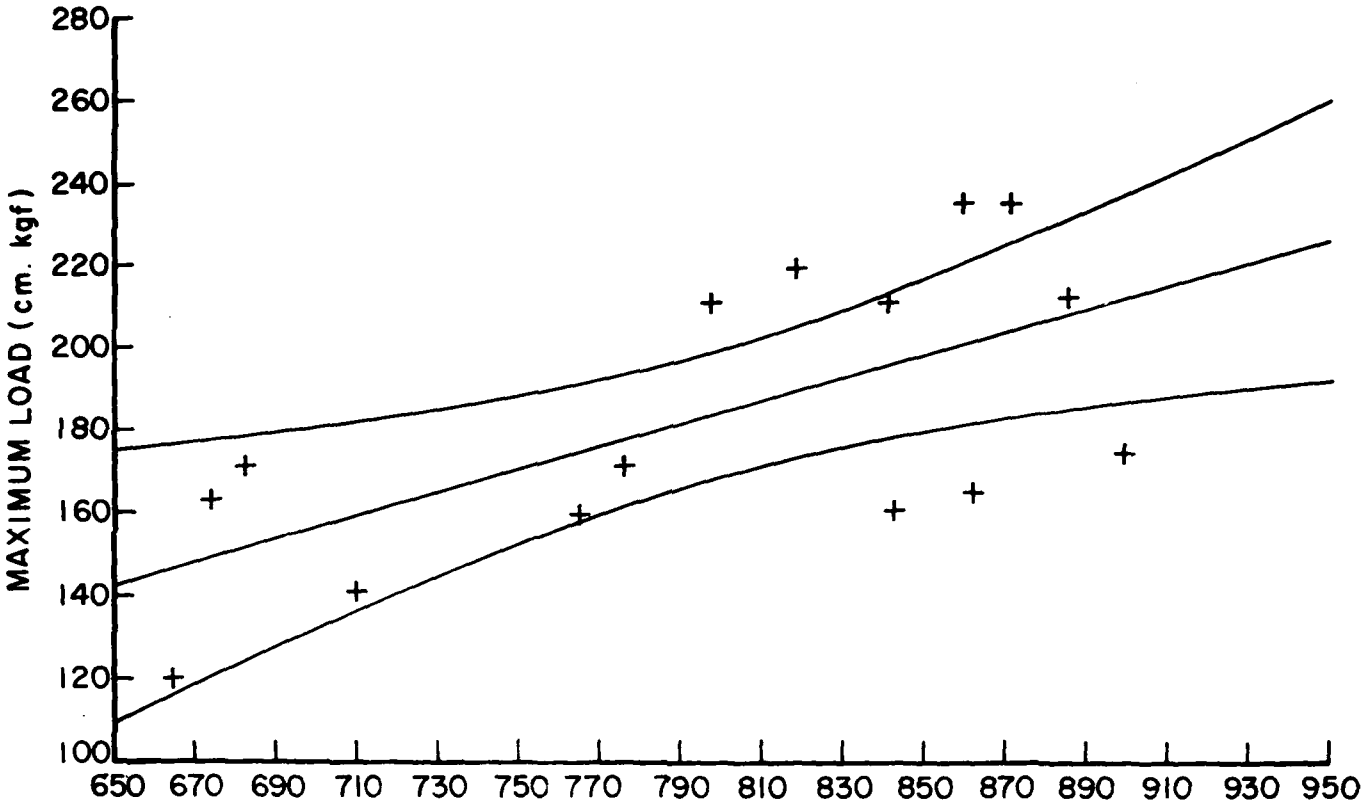
n = 22	$\bar{x}$ = 6204.955	$\bar{y}$ = 124.402	R = 0.8436
x_0 = -16.1300	σ_x = ±1291.631	σ_y = ±34.678	t = 7.0249 ***
y_0 = 0.0226			SE = 19.0829

Figure 10. Tibia, Reconditioned Five Months.



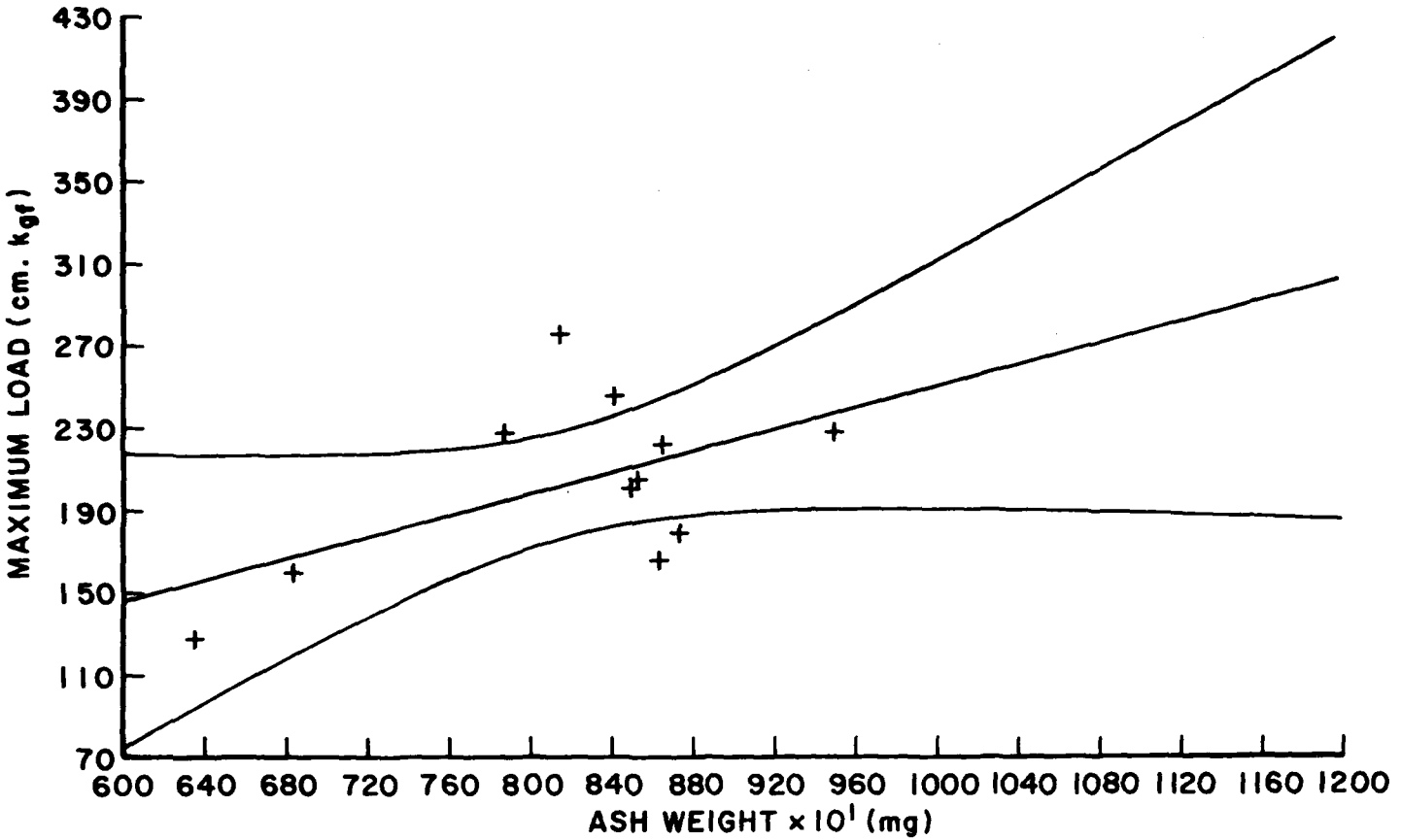
n = 24	$\bar{x}$ = 10278.417	$\bar{y}$ = 255.367	R = 0.8722
x_0 = 62.2802	σ_x = ±2153.898	σ_y = ±46.390	t = 8.3642***
y_0 = 0.0188			SE= 23.2003

Figure 11. Femur, Control.



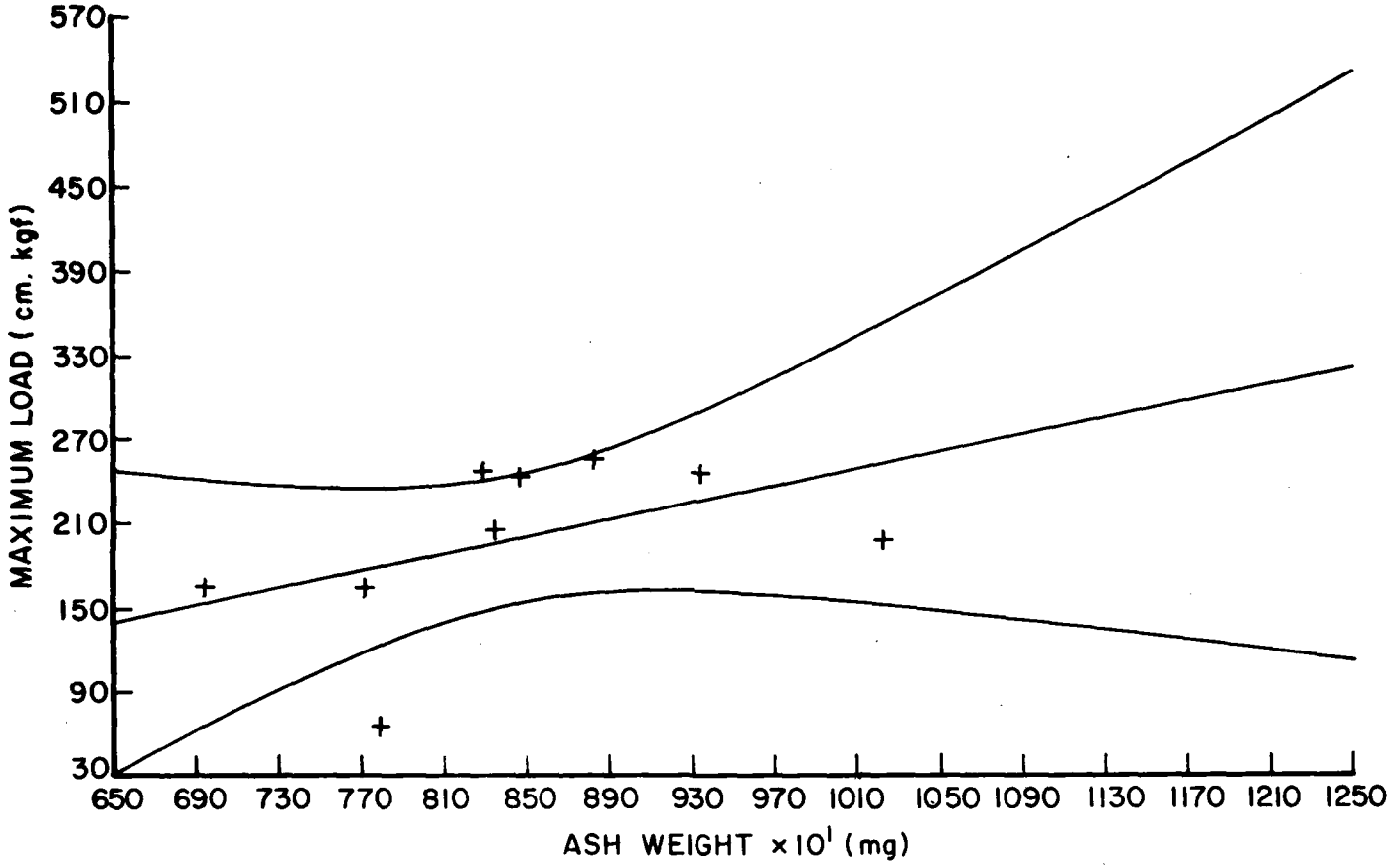
n = 15	$\bar{x}$ = 7966.333	$\bar{y}$ = 183.338	R = 0.6474
x_0 = -40.3397	σ_x = ± 808.426	σ_y = ± 35.061	t = 3.0628**
y_0 = 0.0281			SE= 27.7297

Figure 12. Femur, Immobilized.



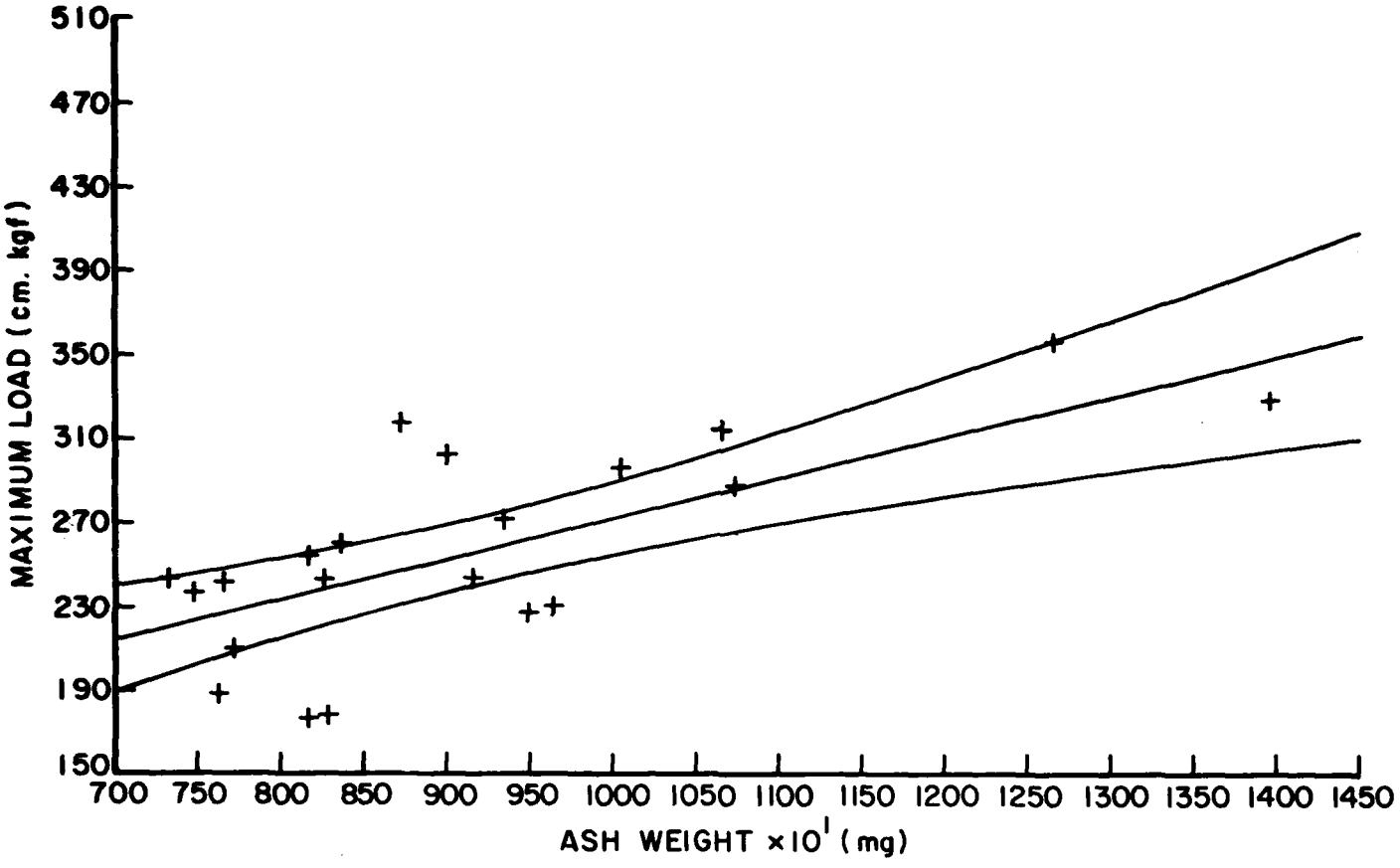
n = 11	$\bar{x}$ = 8205.545	$\bar{y}$ = 203.704	R = 0.5456
x_0 = −9.4659	σ_x = ±895.415	σ_y = ±42.638	t = 1.9529
y_0 = 0.0260			SE = 37.6671

Figure 13. Femur, Exercised Right.



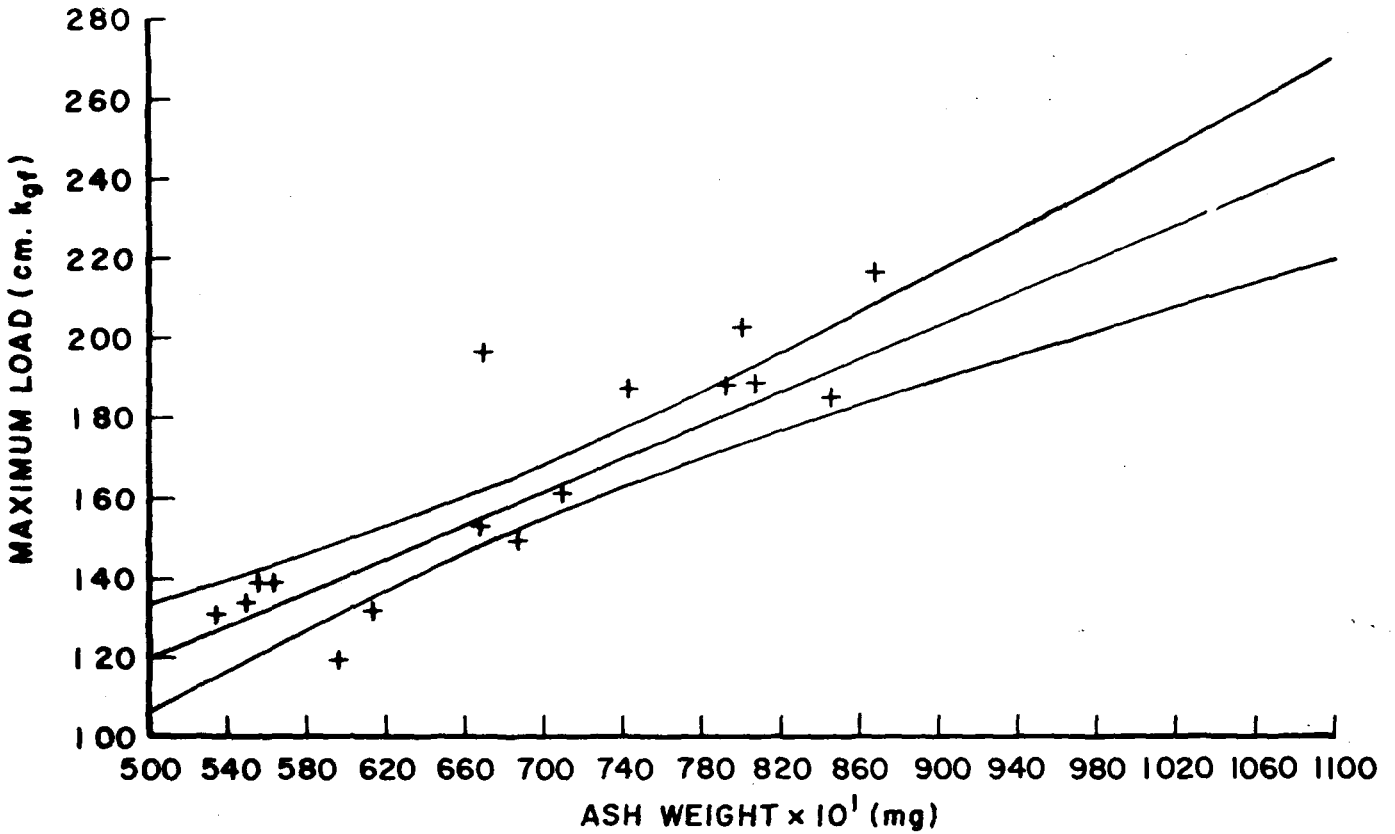
n = 9	$\bar{x}$ = 8441.333	$\bar{y}$ = 199.014	R = 0.4718
x_0 = -55.7098	σ_x = ± 956.688	σ_y = ± 61.194	t = 1.4156
y_0 = 0.0302			SE = 57.6813

Figure 14. Femur, Exercised Left.



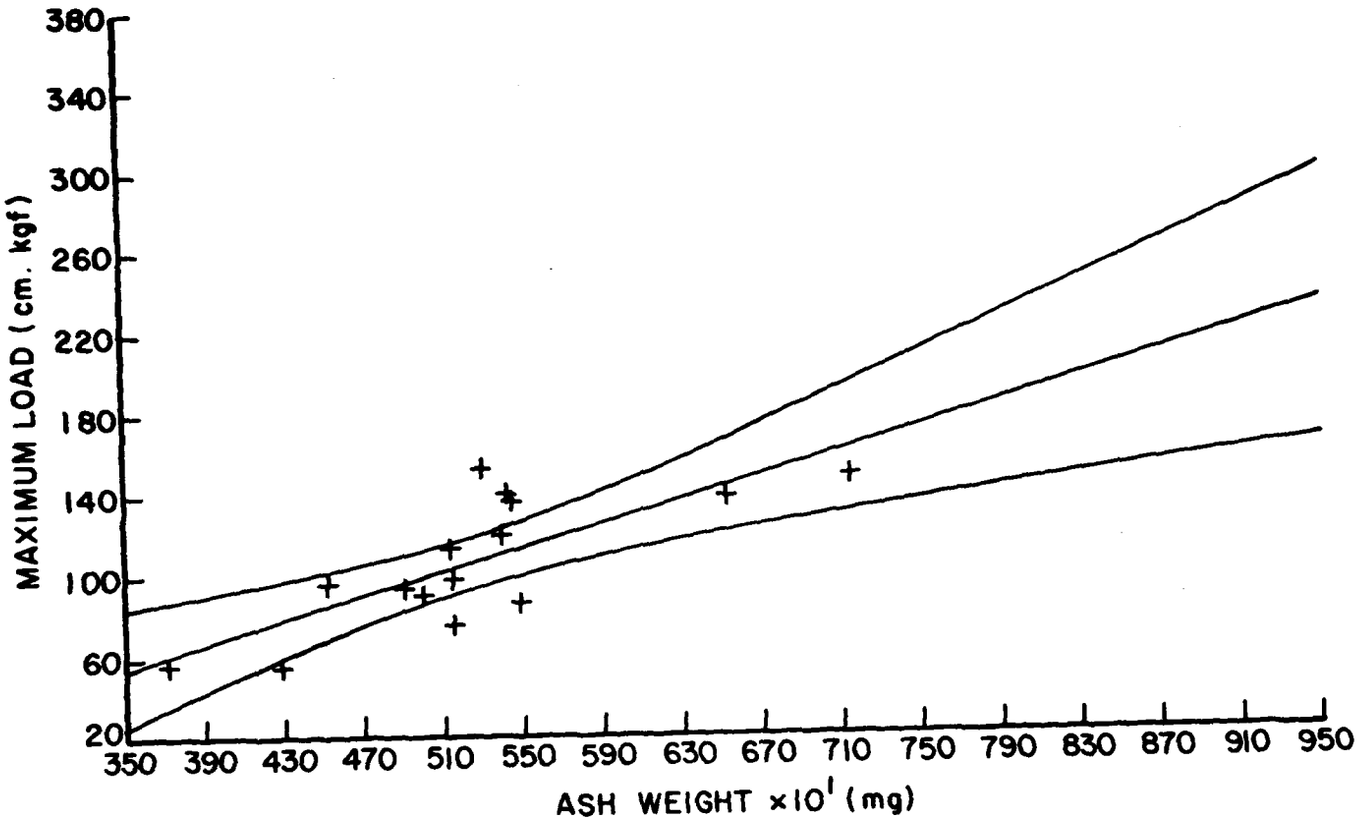
n = 22	$\bar{x}$ = 9302.409	$\bar{y}$ = 258.792	R = 0.7088
x_0 = 80.2991	σ_x = ±1791.361	σ_y = ±48.491	t = 4.4942***
y_0 = 0.0192			SE = 35.0482

Figure 15. Femur, Reconditioned Five Months.



$n = 24$	$\bar{x} = 6982.042$	$\bar{y} = 160.740$	$R = 0.8376$
$x_0 = 15.8017$	$\sigma_x = \pm 1125.550$	$\sigma_y = \pm 27.898$	$t = 7.1903$ ***
$y_0 = 0.0208$			$SE = 15.5840$

Figure 16. Humerus, Control.



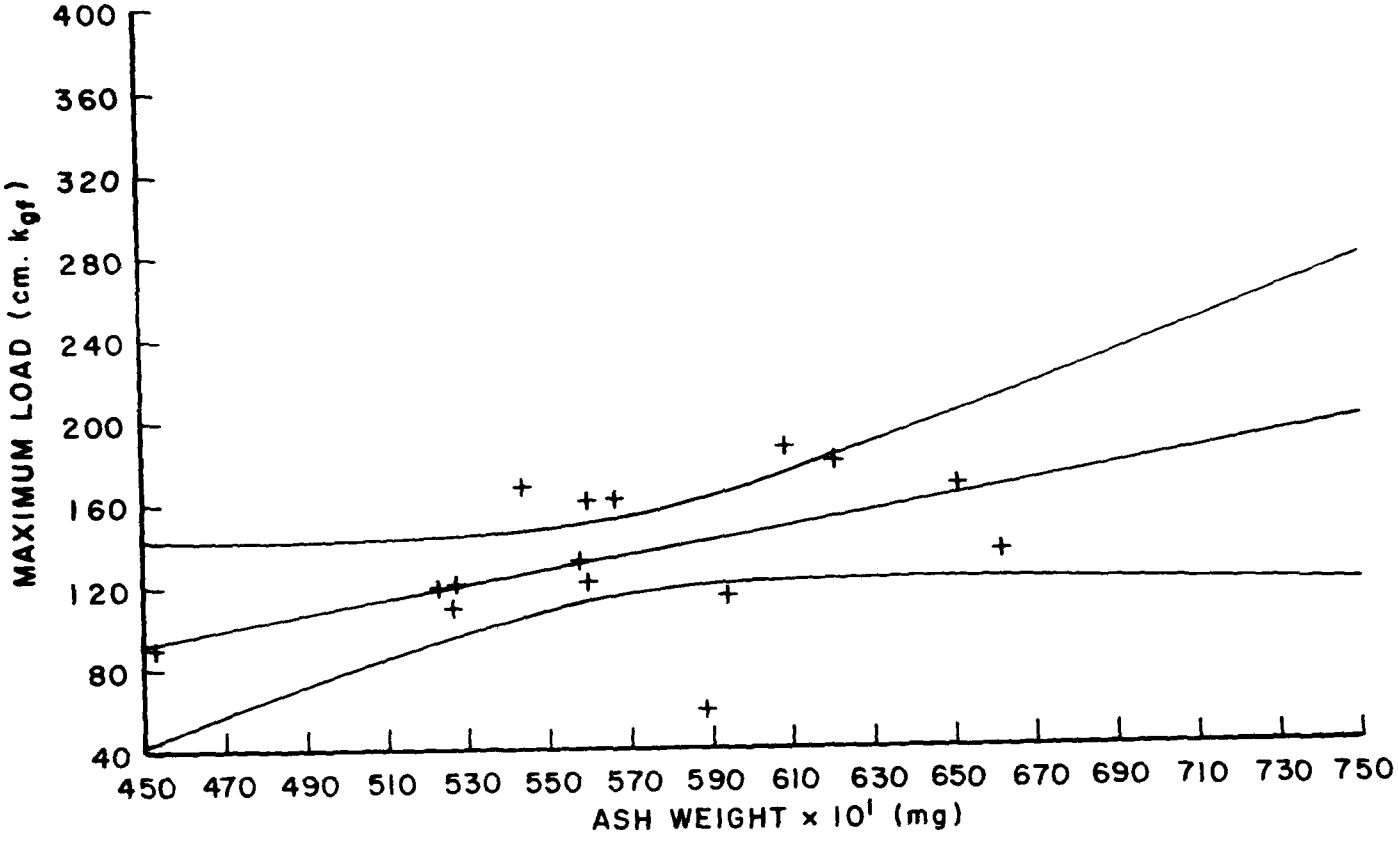
$n = 15$
$x_0 = -47.3058$
$y_0 = 0.0293$

$\bar{x} = 5238.933$ $\quad \sigma_x = \pm 818.459$

$\bar{y} = 106.183$ $\quad \sigma_y = \pm 31.849$

$R = 0.7529$
$t = 4.1246^{**}$
$SE = 21.7528$

Figure 17. Humerus, Immobilized.

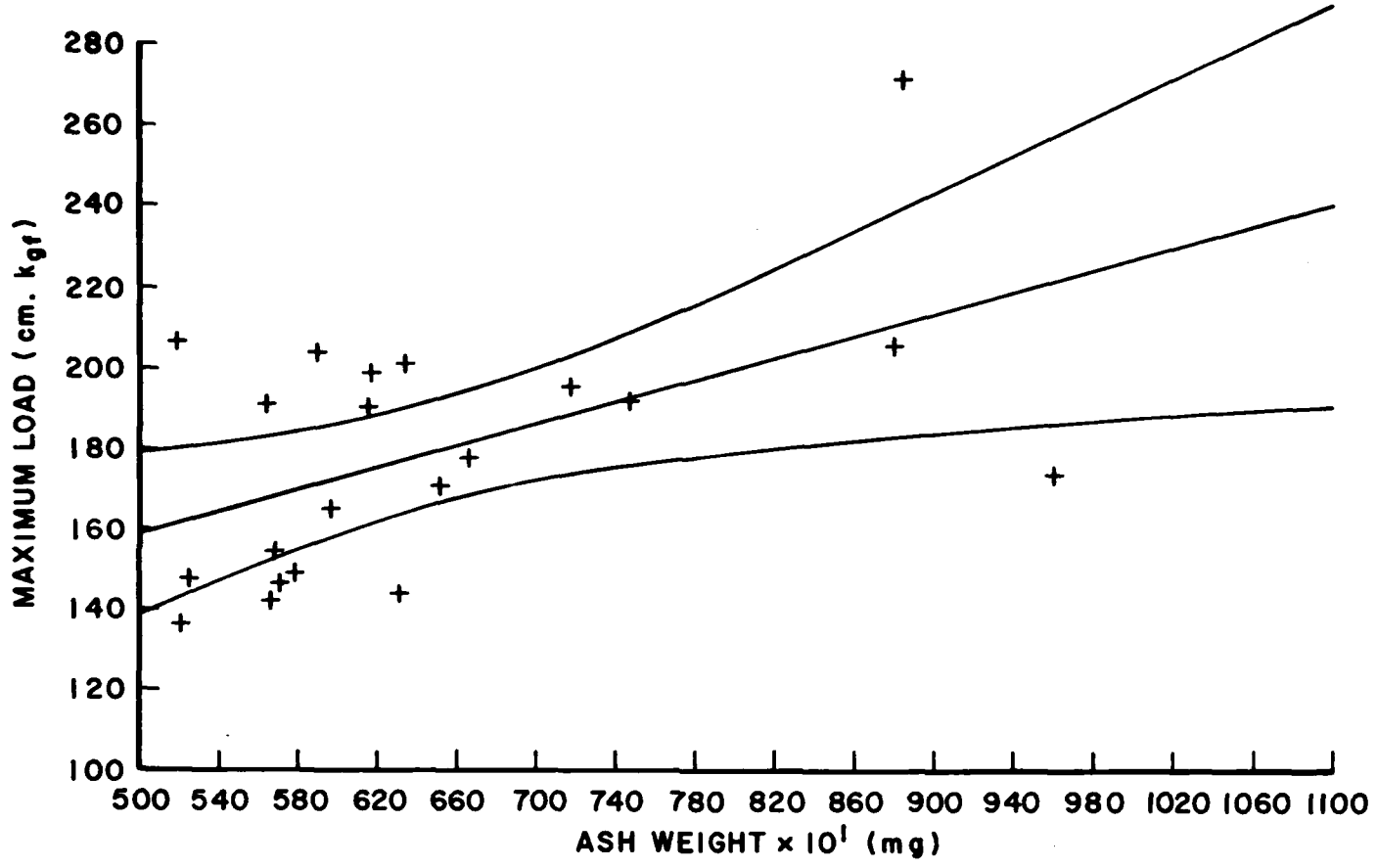


$n = 15$ $\bar{x} = 5641.533$ $\bar{y} = 132.636$ $R = 0.4575$

$x_0 = -65.0544$ $\sigma_x = \pm 477.134$ $\sigma_y = \pm 36.543$ $t = 1.8575$

$y_0 = 0.0350$ $SE = 33.7206$

Figure 18. Humerus, Exercised.



n = 21	$\bar{x}$ = 6492.762	$\bar{y}$ = 179.003	R = 0.5229
x_o = 91.4887	σ_x = ±1244.889	σ_y = ±32.088	t = 2.6741*
y_o = 0.0135			SE= 28.0621

Figure 19. Humerus, Reconditioned Five Months.

Scatter plots were generated for the following bones and test groups:

TIBIA - control, immobilized, exercised right, exercised left, reconditioned five months.

FEMUR - control, immobilized, exercised right, exercised left, reconditioned five months.

HUMERUS - control, immobilized, exercised, reconditioned five months.

The following comparisons were made for each of the above groups:

Maximum Load vs.	Volume
	Dry Weight
	Ash Weight
	Density
	Ash Content
	Percent Ash
	Captivity
	Pre-Weight
	Post-Weight } for certain
	Received Weight } groups only
Rotation to Failure vs.	Volume
	Dry Weight
	Ash Weight
	Density
	Ash Content
	Percent Ash
Energy to Failure vs.	Volume
	Dry Weight
	Ash Weight
	Density
	Ash Content
	Percent Ash

Figures 6 through 19 are the scatter plots of maximum load vs. ash weight for each of the bones and test groups listed above.

APPENDIX D

TABLES OF MEANS, STANDARD DEVIATIONS, NUMBERS OF SUBJECTS, AND RANGE TEST RESULTS FOR IMMOBILIZATION STUDIES

As the experiment progressed, some of the monkeys were eliminated from the control group. This was done for a variety of reasons, e.g., injury to a monkey. The data from these monkeys were deleted from the rest of the control group data but are presented in Tables 12 through 65 for the sake of completeness. Thus, the columns labeled "Control Minus Deleted" in the tables refer to the group which has been designated simply as "Control" throughout the rest of the report.

All of the chemical and ash data contained in this appendix were collected at FRI. All of the histological data were obtained at HFH.

APPENDIX E

STEROID DATA ANALYSIS

A variety of computer programs were used in the analysis of the steroid data. The raw data were obtained directly from oscillographic load vs. extension curves made during tension testing of femur-ligament-tibia preparations taken from rhesus monkeys (see STEROID STUDY in the main report). The load-extension data were analyzed according to the following procedures:

I. Slope Data (Analysis of Covariance)

A. (1) REFMOS, a reformatting program, was run on the original slope data. This program transformed the data into an acceptable format and added BMDO2R (see Appendix A) control cards.

(2) The data for each ligament in the group were submitted to BMDO2R for individual analysis. The BMDO2R provided an equation for each ligament's data. This was usually a cubic fit, although BMDO2R was not forced to fit the data to a cubic equation.

(3) A Standard Error of Estimate Table was compiled from the BMDO2R output. It consisted of standard error of estimates for each variable included in the step-wise regression performed by BMDO2R for each ligament. It provided a condensed version of the regression for determining the amount of error present in the fit of each equation to its respective data.

TABLE 12

FRACTURED BONES, TORSION DATA, TIBIA

	Control Minus Deleted	Deleted Only	Immobilized	Exercised R	Exercised L	Reconditioned 5	Range Test
Max. Lin. Load ($cm \cdot kg_f$)	121.83 ± 21.04 (23)	112.29 ± 22.68 (9)	89.909 ± 27.46 (19)	85.136 ± 21.25 (10)	92.181 ± 21.25 (8)	118.69 ± 34.69 (22)	C-I** C-ER** C-EL* I-R** R-ER* R-EL*
Max. Load ($cm \cdot kg_f$)	131.92 ± 22.66 (23)	119.29 ± 21.65 (9)	94.043 ± 31.10 (19)	91.981 ± 22.00 (10)	93.144 ± 22.42 (8)	124.40 ± 34.68 (22)	C-I** C-ER** C-EL** I-R* R-ER* R-EL*
Rot. Max. Lin. Load (Deg.)	37.270 ± 4.872 (23)	41.777 ± 2.179 (9)	32.783 ± 6.788 (19)	28.090 ± 5.464 (10)	28.654 ± 2.684 (8)	29.109 ± 4.764 (22)	C-I** C-ER*** C-EL*** C-R***
Rot. Fail (Deg.)	46.328 ± 8.273 (23)	51.047 ± 6.944 (9)	37.342 ± 8.870 (19)	34.276 ± 9.121 (10)	30.065 ± 3.815 (8)	33.230 ± 8.508 (22)	C-I*** C-ER*** C-EL*** C-R***
Energy Max. Lin. Load ($cm \cdot kg_f$)	41.417 ± 8.980 (23)	43.342 ± 10.61 (9)	27.804 ± 10.31 (19)	25.943 ± 8.735 (10)	23.706 ± 6.918 (8)	32.560 ± 12.24 (22)	C-I*** C-ER*** C-EL*** C-R**
Energy Fail ($cm \cdot kg_f$)	62.433 ± 17.44 (23)	60.007 ± 14.62 (9)	36.314 ± 19.30 (19)	34.684 ± 13.59 (10)	26.096 ± 9.018 (8)	41.244 ± 18.24 (22)	C-I*** C-ER*** C-EL*** C-R***

TABLE 13

FRACTURED BONES, TORSION DATA, FEMUR

	Control Minus Deleted	Deleted Only	Immobilized	Exercised R	Exercised L	Reconditioned 5	Range Test
Max. Lin. Load ($cm \cdot kg_f$)	236.49 ± 44.48 (24)	226.21 ± 41.50 (10)	170.43 ± 31.75 (17)	183.21 ± 40.48 (11)	170.44 ± 56.63 (10)	247.20 ± 47.94 (22)	C-I*** C-ER** C-EL*** I-R*** R-ER*** R-EL***
Max. Load ($cm \cdot kg_f$)	255.37 ± 46.39 (24)	241.63 ± 43.75 (10)	189.66 ± 37.35 (17)	203.70 ± 42.64 (11)	193.60 ± 60.18 (10)	258.79 ± 48.49 (22)	C-I*** C-ER** C-EL** I-R*** R-ER** R-EL**
Rot. Max. Lin. Load (deg.)	36.186 ± 5.602 (24)	36.473 ± 2.211 (10)	34.670 ± 5.333 (17)	33.262 ± 2.761 (11)	31.253 ± 10.39 (10)	32.462 ± 4.323 (22)	
Rot. Fail (deg.)	44.918 ± 8.055 (24)	43.443 ± 4.688 (10)	45.895 ± 11.05 (17)	43.153 ± 9.010 (11)	42.626 ± 14.79 (10)	37.114 ± 7.631 (22)	C-R* I-R*
Energy Max. Lin. Load ($cm \cdot kg_f$)	78.515 ± 16.48 (24)	74.725 ± 17.81 (10)	55.015 ± 14.87 (17)	55.190 ± 14.82 (11)	54.336 ± 29.10 (10)	72.149 ± 13.82 (22)	C-I*** C-ER** C-EL** I-R** R-ER** R-EL*
Energy Fail ($cm \cdot kg_f$)	115.25 ± 34.03 (24)	105.76 ± 23.50 (10)	92.837 ± 36.67 (17)	89.282 ± 32.36 (11)	89.058 ± 49.42 (10)	92.506 ± 27.40 (22)	

TABLE 14

FRACTURED BONES, TORSION DATA, HUMERUS

	Control Minus Deleted	Deleted Only	Immobilized	Exercised	Reconditioned 5	Range Test
Max. Lin. Load ($cm \cdot kg_f$)	151.02 ± 28.90 (24)	156.50 ± 39.36 (10)	95.139 ± 24.89 (15)	121.98 ± 39.16 (15)	170.87 ± 31.04 (21)	C-I*** C-E** C-R* I-E* I-R*** R-E***
Max. Load ($cm \cdot kg_f$)	160.74 ± 27.90 (24)	168.05 ± 46.75 (10)	106.18 ± 31.85 (15)	132.64 ± 36.54 (15)	179.00 ± 32.09 (21)	C-I*** C-E** I-E* I-R*** R-E***
Rot. Max. Lin. Load (deg.)	36.724 ± 5.055 (24)	39.414 ± 2.417 (10)	34.147 ± 7.046 (15)	34.049 ± 7.564 (15)	31.911 ± 4.374 (21)	
Rot. Fail (deg.)	43.558 ± 8.885 (24)	45.457 ± 3.402 (10)	45.432 ± 13.02 (15)	44.761 ± 13.63 (15)	36,675 ± 8.843 (21)	
Energy Max. Lin. Load ($cm \cdot kg_f$)	50.405 ± 8.856 (24)	56.016 ± 14.30 (10)	29.597 ± 7.284 (15)	40.334 ± 18.44 (15)	48.989 ± 9.253 (21)	C-I*** C-E* I-E* I-R*** R-E*
Energy Fail ($cm \cdot kg_f$)	69.036 ± 20.38 (24)	70.876 ± 21.90 (10)	49.683 ± 25.36 (15)	61.708 ± 26.00 (15)	62.699 ± 23.36 (21)	

TABLE 15

FRACTURED BONES, ASH DATA, TIBIA

	Control Minus Deleted	Deleted Only	Immobilized	Exercise R	Exercise L	Reconditioned 5	Range Test
Volume (mm^3)	6380.1 ±1249 (24)	6520.0 ±1553.0 (10)	5615.1 ±1144 (24)	5602.5 ±835.2 (11)	5638.1 ±450.8 (11)	5862.1 ±1201 (22)	
Dry Weight (mg)	10,063 ±1743 (24)	10810.0 ±2667.4 (10)	8431.4 ±1423 (24)	8270.2 ±789.1 (11)	8288.5 ±777.0 (11)	9077.1 ±1844 (22)	C-I* C-ER* C-EL* C-R*
Ash Weight (mg)	6806.5 ±1215 (24)	7341.4 ±1843.6 (10)	5708.0 ±989.2 (24)	5580.8 ±564.4 (11)	5616.0 ±547.3 (11)	6205.0 ±1292 (22)	C-I* C-ER* C-EL*
Density (mg/mm^3)	1.5846 ±.0985 (24)	1.6520 ±.07983 (10)	1.5204 ±.1587 (24)	1.4936 ±.1685 (11)	1.4727 ±.1194 (11)	1.5527 ±.08447 (22)	
Ash Content (mg/mm^3)	1.0717 ±.0672 (24)	1.1210 ±.06155 (10)	1.0288 ±.1065 (24)	1.0082 ±.1258 (11)	.99818 ±.0869 (11)	1.0609 ±.0669 (22)	
Per Cent Ash (%)	67.579 ±1.003 (24)	67.860 ± .72908 (10	67.667 ±.6598 (24)	67.445 ±1.109 (11)	67.755 ±1.244 (11)	68.273 ±1.023 (22)	

TABLE 16

FRACTURED BONES, ASH DATA, FEMUR

	Control Minus Deleted	Deleted Only	Immobilized	Exercise R	Exercise L	Reconditioned 5	Range Test
Volume (mm^3)	8985.5 ±2203 (24)	6988.9 ± 3126.5 (9)	6775.3 ±647.3 (18)	7368.0 ±877.7 (11)	6824.1 ±2440 (11)	7960.5 ±1491 (22)	C-I*** C-ER* C-EL* C-R*
Dry Weight (mg)	14,828 ±3009 (24)	14517. ± 3371.1 (10)	11,571 ±1084 (18)	11,839 ±1276 (11)	11,047 ±3850 (11)	13,260 ± 2448 (22)	C-I*** C-ER** C-EL** C-R*
Ash Weight (mg)	10,278 ±2154 (24)	10116. ± 2389.2 (10)	8037.8 ±758.1 (18)	8205.5 ±895.4 (11)	7693.9 ±2692 (11)	9302.4 ±1791 (22)	C-I*** C-ER** C-EL** C-R*
Density (mg/mm^3)	1.6629 ±.1162 (24)	1.7490 ± .0415 (10)	1.7106 ±.0763 (18)	1.6100 ±.0769 (11)	1.4773 ±.4948 (11)	1.6695 ±.0773 (22)	
Ash Content (mg/mm^3)	1.1542 ±.0828 (24)	1.2160 ± .0313 (10)	1.1872 ±.0548 (18)	1.1173 ±.0636 (11)	1.0282 ±.3453 (11)	1.1709 ±.0673 (22)	
Per Cent Ash (%)	69.400 ±.8658 (24)	69.61 .4483 (10)	69.472 ±.4701 (18)	69.300 ±1.267 (11)	63.300 ±21.02 (11)	70.082 ±1.145 (22)	

TABLE 17

FRACTURED BONES, ASH DATA, HUMERUS

	Control Minus Deleted	Deleted Only	Immobilized	Exercise	Reconditioned 5	Range Test
Volume (mm^3)	6142.0 ±1087 (24)	6110.0 ±1452.6 (10)	4492.2 ±774.4 (16)	5139.5 ±666.2 (22)	5674.6 ±1058 (22)	C-I*** C-E** I-E* I-R***
Dry Weight (mg)	10,109 ±1553 (24)	10556. ±2529.3 (10)	7491.2 ±1275 (16)	8075.3 ±1001 (22)	9300.2 ±1667 (22)	C-I*** C-E*** I-R*** R-E**
Ash Weight (mg)	6982.0 ±1126 (24)	7307.5 ±1769.7 (10)	5138.4 ±887.0 (16)	5605.3 ±712.0 (22)	6486.4 ±1215 (22)	C-I*** C-E*** I-R*** R-E**
Density (mg/mm^3)	1.6525 ±.07914 (24)	1.7260 ±.0628 (10)	1.6706 ±.1136 (16)	1.5791 ±.1528 (22)	1.6427 ±.0513 (22)	
Ash Content (mg/mm^3)	1.1408 ±.0517 (24)	1.1970 ±.0452 (10)	1.1463 ±.0761 (16)	1.0959 ±.1137 (22)	1.1436 ±.04467 (22)	
Per Cent Ash (%)	69.008 ±1.070 (24)	69.21 .6641 (10)	68.562 ±.8180 (16)	69.400 ±1.094 (22)	69.641 ±1.039 (22)	I-E* I-R*

TABLE 18

FRACTURED BONES, CHEMICAL DATA, TIBIA

	Control Minus Deleted	Delcted Only	Immobilized	Exercise R	Exercise L	Reconditioned 5	Range Test
Ca Dry Wt. (mg/g)	259.81 ±25.36 (16)	245.40 20.876 (10)	243.79 ±23.39 (24	238.18 ±35.74 (11)	239.70 31.14 (10)	223.90 ±11.06 (10)	C-R•
Ca Vol. (mg/cm^3)	419.81 ±41.28 (16)	406.80 51.155 (10)	370.83 ±53.66 (24	357.91 ±83.85 (11)	357.90 61.64 (10)	341.90 ±27.34 (10)	C-R••
P Dry Wt (mg/g)	117.88 ±8.861 (16)	113.80 3.7357 (10)	116.46 ±4.452 (24	116.73 ±5.140 (11)	115.36 ±6.120 (11)	116.50 ±3.837 (10)	
P Vol. (mg/cm^3)	191.19 ±22.08 (16)	188.00 9.7866 (10)	177.25 ±20.08 (24	174.45 ±24.09 (11)	169.82 ±18.72 (11)	177.40 ±13.38 (10)	
Mg Dry Wt. (mg/g)	3.2038 ±.4011 (16)	3.0400 .32066 (10)	3.3517 ±.4151 (24	3.4236 ±.3011 (11)	3.3960 .2034 (10)	3.3830 ±.2148 (10)	
Mg Vol. (mg/cm^3)	5.1762 ±.6432 (16)	5.0260 .64019 (10)	5.0996 ±.8516 (24	5.1009 ±.5568 (11)	5.0460 .3277 (10)	5.1280 ±.3170 (10)	
Ca/P	2.2250 ±.3480 (16)	2.1590 .20867 (10)	2.0958 ±.2178 (24	2.0373 ±.2631 (11	2.0720 .2229 (10)	1.9230 ±.1165 (10)	
Ca/Mg	81.687 ±7.717 (16)	81.320 8.8365 (10)	73.671 ±10.51 (24	70.200 ±13.38 (11	70.24 10.34 (10)	66.510 ±6.506 (10)	C-I• C-ER• C-RL• C-R•• D-R•

TABLE 19

FRACTURED BONES, CHEMICAL DATA, FEMUR

	Control Minus Deleted	Deleted Only	Immobilized	Exercise R	Exercise L	Reconditioned 5	Range Test
Ca Dry Wt. (mg/g)	261.38 ±36.23 (16)	247.10 ±33.85 (10)	249.39 ±20.40 (18)	242.18 ±18.86 (11)	235.00 21.41 (10)	243.10 ±24.01 (10)	
Ca Vol. (mg/cm^3)	444.25 ±61.70 (16)	437.2 ±65.89 (10)	426.56 ±43.18 (18)	390.09 ±35.91 (11)	381.60 39.44 (10)	403.20 ±36.97 (10)	C-ER* C-EL*
P Dry Wt. (mg/g)	123.88 ±5.909 (16)	118.50 ±4.7199 (10)	120.89 ±8.844 (18)	120.18 ±6.080 (11)	117.50 5.191 (10)	119.00 ±3.162 (10)	
P Vol. (mg/cm^3)	212.44 ±13.57 (16)	207.40 ±10.384 (10)	206.67 ±17.80 (18)	193.82 ±16.38 (11)	189.80 10.05 (10)	197.80 ±14.71 (10)	C-ER* C-EL**
Mg Dry Wt. (mg/g)	3.1875 ±.3809 (16)	3.1180 ±.33008 (10)	3.5239 ±.5697 (18)	3.5745 ±.2660 (11)	3.4750 .1483 (10)	3.5540 ±.2550 (10)	
Mg Vol. (mg/cm^3)	5.4606 ±.5840 (16)	5.46 .6654 (10)	6.0278 ±1.030 (18)	5.7636 ±.5284 (11)	5.6430 .3494 (10)	5.1960 ±.6024 (10)	
Ca/P	2.1019 ±.3514 (16)	2.0820 .2567 (10)	2.0717 ±.2215 (18)	2.0182 ±.1602 (11)	2.0010 .1901 (10)	2.0490 ±.2493 (10)	
Ca/Mg	81.500 ±9.115 (16)	79.200 6.5671 (10)	72.056 ±10.13 (18)	68.036 ±6.881 (11)	67.74 6.583 (10)	68.660 ±7.877 (10)	C-I** C-ER** C-EL** C-R** D-I* D-ER* D-EL* D-R*

TABLE 20

FRACTURED BONES, CHEMICAL DATA, HUMERUS

Control Minus Deleted	Deleted Only	Immobilized	Exercise	Reconditioned 5	Range Test	
270.75 ±26.18 (16)	251.9 ±14.50 (10)	255.19 ±33.07 (16)	226.32 ±14.14 (22)	249.60 ±15.00 (10)	C-E*** D-E* I-E** E-R*	Ca Dry Wt. (mg/g)
455.25 ±47.63 (16)	435.0 ±29.84 (10)	435.00 ±73.57 (16)	358.27 ±50.63 (22)	408.40 ±25.61 (10)	C-E*** D-E** I-E** E-R*	Ca Vol. (mg/cm^3)
116.94 ±5.916 (16)	120.30 ± 5.2292 (10)	119.31 ±5.736 (16)	116.45 ±5.289 (22)	120.60 ±4.881 (10)		P Dry Wt. (mg/g)
195.94 ±13.69 (16)	207.60 ±12.186 (10)	203.44 ±25.02 (16)	184.00 ±21.11 (22)	197.30 ±9.068 (10)	D-E* I-E*	P Vol. (mg/cm^3)
3.4038 ±.3338 (16)	3.3940 ±.48204 (10)	3.5700 ±.4868 (16)	3.4664 ±.2248 (22)	3.5120 ±.2026 (10)		Mg Dry Wt. (mg/g)
5.6781 ±.6074 (16)	5.8750 .91606 (10)	6.0981 ±1.173 (16)	5.4723 ±.6945 (22)	5.7500 ±.3322 (10)		Mg Vol. (mg/cm^3)
2.3231 ±.3003 (16)	2.0980 .15845 (10)	2.1369 ±.2457 (16)	1.9455 ±.1445 (22)	2.0730 ±.1323 (10)	C-D* C-I* C-E*** C-R* I-E*	Ca/P
80.050 ±9.527 (16)	75.480 10.917 (10)	72.019 ±8.447 (16)	65.486 ±5.127 (22)	71.130 ±2.960 (10)	C-I* C-E*** C-R* D-E** I-E*	Ca/Mg

TABLE 21

WHOLE BONES, ASH DATA, TIBIA

	Control	Immobilized	Reconditioned 12	Range Test
Volume (mm^3)	21,540 ± 2339.2 (12)	19,645 ± 678.8 (6)	23,170 ± 2353.8 (3)	
Dry Weight (mg)	17,771 ± 2209.2 (12)	16,632 ± 1457.2 (6)	19,325 ± 533.5 (3)	
Ash Weight (mg)	11,255 ± 1421.8 (12)	10,526 ± 833.1 (6)	12,481 ± 467.0 (3)	
Density (mg/mm^3)	.82917 ± .0906 (12)	.84667 ± .0698 (6)	.84333 ± .09074 (3)	
Ash Content (mg/mm^3)	.52583 ± .05712 (12)	.53500 ± .0437 (6)	.54000 ± .05568 (3)	
Per Cent Ash (%)	63.317 ± 1.376 (12)	63.317 ± 1.207 (6)	64.567 ± 1.234 (3)	

TABLE 22

WHOLE BONES, CHEMICAL DATA, TIBIA

	Control	Immobilized	Range Test
Ca Dry Weight (mg/g)	239.33 ± 13.88 (12)	248.83 ± 15.94 (6)	
Ca Volume (mg/cm3)	197.92 ± 16.94 (12)	211.33 ± 26.28 (6)	
P Dry Weight (mg/g)	109.92 ± 4.316 (12)	104.33 ± 2.733 (6)	C-I*
P Volume (mg/cm^3)	91.083 ± 10.09 (12)	88.500 ± 8.068 (6)	
Mg Dry Weight (mg/g)	3.3308 ± .0728 (12)	3.2333 ± .1449 (6)	
Mg Volume (mg/cm^3)	2.7600 ± .3073 (12)	2.7333 ± .1813 (6)	
Ca/P	2.1900 ± .1365	2.3867 ± .1821 (6)	C-I*
Ca/Mg	71.858 ± 4.011	77.083 ± 5.334 (6)	C-I*

TABLE 23

WHOLE BONES, ASH DATA, FEMUR

	Control	Immobilized	Reconditioned 12	Range Test
Volume (mm^3)	30,951 ± 3717.7 (12)	29,002 ± 3399 (12)	35,327 ± 4119 (3)	I-R12•
Dry Weight (mg)	27,189 ± 1851.2 (12)	24,640 ± 2314 (12)	34,156 ± 4028 (3)	C-I• C-R12••• I-R12•••
Ash Weight (mg)	17,140 ± 1119.5 (12)	15,765 ± 1541 (12)	22,277 ± 2484 (3)	C-I• C-R12••• I-R12•••
Density (mg/mm^3)	.88833 ± .09514 (12)	.85500 ± .0836 (12)	.97667 ± .1644 (3)	
Ash Content (mg/mm^3)	.55917 ± .06346 (12)	.54917 ± .0592 (12)	.63333 ± .1002 (3)	
Per Cent Ash (%)	63.117 ± 3.076 (12)	63.975 ± 1.533 (12)	65.233 ± .5860 (3)	

TABLE 24

WHOLE BONES, CHEMICAL DATA, FEMUR

	Control	Immobilized	Range Test
Ca Dry Weight (mg/g)	251.50 ± 21.51 (12)	246.08 ± 18.07 (12)	
Ca Volume (mg/cm3)	222.00 ± 20.31 (12)	210.67 ± 28.45 (12)	
P Dry Weight (mg/g)	103.08 ± 4.010 (12)	107.33 ± 6.665 (12)	
P Volume (mg/cm^3)	91.583 ±10.78 (12)	91.917 ± 10.13 (12)	
Mg Dry Weight (mg/g)	3.5400 ± .1423 (12)	3.4425 ± .2045 (12)	
Mg Volume (mg/cm^3)	3.1358 ± .2658 (12)	2.9400 ± .2418 (12)	
Ca/P	2.4417 ± .2056 (12)	2.3000 ±.2128 (12)	
Ca/Mg	71.108 ± 6.165 (12)	71.856 ± 8.011 (12)	

TABLE 25

WHOLE BONES, ASH DATA, HUMERUS

	Control	Immobilized	Reconditioned 12	Range Test
Volume (mm^3)	20,116 ± 2201.5 (12)	18,875 ± 2050 (12)	22,647 ± 4451 (3)	
Dry Weight (mg)	18,331 ± 1930.2 (12)	17,323 ± 1982 (12)	22,788 ± 3713 (3)	C-R12** I-R12**
Ash Weight (mg)	11,715 ± 1360.3 (12)	10,966 ± 1382 (12)	15,168 ± 2676 (3)	C-R12*** I-R12**
Density (mg/mm^3)	.91417 ± .0757 (12)	.92750 ± .1248 (12)	1.0133 ± .05507 (3)	
Ash Content (mg/mm^3)	.58333 ± .05221 (12)	.58750 ± .0923 (12)	.67000 ± .0173 (3)	
Per Cent Ash (%)	63.867 ± 1.616 (12)	63.217 ± 1.754 (12)	66.4671 ± 1.457 (3)	C-R12* I-R12*

TABLE 26

WHOLE BONES, CHEMICAL DATA, HUMERUS

	Control	Immobilized	Range Test
Ca Dry Weight (mg/g)	242.00 ± 10.43 (12)	251.58 ± 18.86 (12)	
Ca Volume (mg/cm3)	221.00 ± 16.00 (12)	234.33 ± 41.41 (12)	
P Dry Weight (mg/g)	111.17 ± 5.875 (12)	109.00 ± 6.836 (12)	
P Volume (mg/cm^3)	101.58 ± 7.597 (12)	101.75 ± 16.25 (12)	
Mg Dry Weight (mg/g)	3.3933 ± .2049 (12)	3.4492 ± .2113 (12)	
Mg Volume (mg/cm^3)	3.0967 ± .2210 (12)	3.1733 ± .3175 (12)	
Ca/P	2.1850 ± .1585 (12)	2.3125 ± .1604 (12)	
Ca/Mg	71.467 ± 3.627 (12)	73.383 ± 8.820 (12)	

TABLE 27

WHOLE BONES, ASH DATA, RADIUS

	Control	Immobilized	Range Test
Volume (mm^3)	7683.8 ± 1077.5 (12)	7481.0 ± 808.1 (12)	
Dry Weight (mg)	7660.9 ± 998.5 (12)	7765.5 ± 842.1 (12)	
Ash Weight (mg)	4882.8 ± 637.3 (12)	4954.1 ± 543.8 (12)	
Density (mg/mm^3)	1.0017 ± .06837 (12)	1.0492 ± .1370 (12)	
Ash Content (mg/mm^3)	.63833 ± .04933 (12)	.67000 ± .0967 (12)	
Per Cent Ash (%)	63.658 ± 1.573 (12)	63.792 ± 1.383 (12)	

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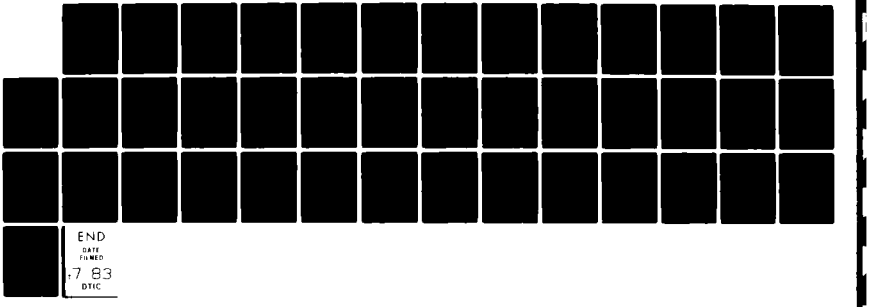

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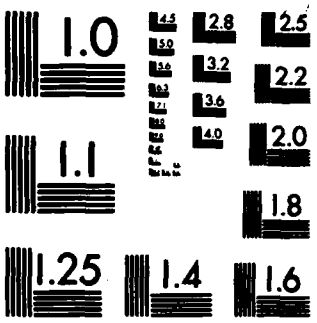


TABLE 28

WHOLE BONES, CHEMICAL DATA, RADIUS

	Control	Immobilized	Range Test
Ca Dry Weight (mg/g)	247.92 ± 20.02 (12)	243.67 ± 24.50 (12)	
Ca Volume (mg/cm^3)	248.17 ± 25.62 (12)	256.67 ± 47.24 (12)	
P Dry Weight (mg/g)	110.50 ± 2.970 (12)	108.83 ± 5.797 (12)	
P Volume (mg/cm^3)	110.75 ± 7.864 (12)	116.92 ± 22.01 (12)	
Mg Dry Weight (mg/g)	3.4433 ± .2052 (12)	3.4250 ± .1700 (12)	
Mg Volume (mg/cm^3)	3.4458 ± .3019 (12)	3.5725 ± .3994 (12)	
Ca/P	2.2425 ± .1779 (12)	2.2408 ± .2155 (12)	
Ca/Mg	71.992 ± 4.033 (12)	71.475 ± 9.314 (12)	

TABLE 29

WHOLE BONES, ASH DATA, FIBULA

	Control	Immobilized	Range Test
Volume (mm^3)	3672.8 ± 683.7 (12)	3323.1 ± 149.3 (12)	
Dry Weight (mg)	4107.6 ± 723.8 (12)	3814.8 ± 299.2 (12)	
Ash Weight (mg)	2655.9 ± 465.7 (12)	2458.7 ± 207.5 (12)	
Density (mg/mm^3)	1.1242 ± .1000 (12)	1.1508 ± .1059 (12)	
Ash Content (mg/mm^3)	.72583 ± .0688 (12)	.74167 ± .0698 (12)	
Per Cent Ash (%)	64.658 ± 1.032 (12)	64.417 ± 1.403 (12)	

TABLE 30

WHOLE BONES, CHEMICAL DATA, FIBULA

	Control	Immobilized	Range Test
Ca Dry Weight (mg/g)	249.75 ± 11.96 (12)	240.33 ± 19.52 (12)	
Ca Volume (mg/cm3)	280.00 ± 20.09 (12)	277.58 ± 40.08 (12)	
P Dry Weight (mg/g)	108.92 ± 4.144 (12)	110.00 ± 2.860 (12)	
P Volume (mg/cm^3)	122.42 ± 10.88 (12)	126.00 ± 13.74 (12)	
Mg Dry Weight (mg/g)	3.5075 ± .2124 (12)	3.3533 ± .1840 (12)	
Mg Volume (mg/cm^3)	3.9358 ± .3436 (12)	3.8450 ± .2383 (12)	
Ca/P	2.2967 ± .1310 (12)	2.1842 ± .1640 (12)	
Ca/Mg	71.358 ± 4.142 (12)	71.967 ± 7.646 (12)	

TABLE 31

WHOLE BONES, ASH DATA, ULNA

	Control	Immobilized	Range Test
Volume (mm^3)	8806.8 ± 1292.5 (12)	8121.7 ± 1045 (12)	
Dry Weight (mg)	9368.8 ± 942.2 (12)	8705.9 ± 897.8 (12)	
Ash Weight (mg)	6074.6 ± 632.4 (12)	5577.3 ± 657.6 (12)	
Density (mg/mm^3)	1.0733 ± .09228 (12)	1.0867 ± .1533 (12)	
Ash Content (mg/mm^3)	.69583 ± .0608 (12)	.69000 ± .1121 (12)	
Per Cent Ash (%)	64.817 ± 1.452 (12)	63.967 ± 1.759 (12)	

TABLE 32

WHOLE BONES, CHEMICAL DATA, ULNA

	Control	Immobilized	Range Test
Ca Dry Weight (mg/g)	256.25 ± 19.45 (12)	244.25 ± 15.96 (12)	
Ca Volume (mg/cm3)	273.75 ± 15.21 (12)	266.42 ± 44.60 (12)	
P Dry Weight (mg/g)	114.25 ± 5.578 (12)	109.83 ± 6.337 (12)	
P Volume (mg/cm^3)	122.58 ± 10.61 (12)	119.75 ± 21.23 (12)	
Mg Dry Weight (mg/g)	3.5475 ± .2152 (12)	3.4167 ± .1883 (12)	
Mg Volume (mg/cm^3)	3.8000 ± .2903 (12)	3.6908 ± .4197 (12)	
Ca/P	2.2425 ± .1339 (12)	2.2283 ± .1466 (12)	
Ca/Mg	72.342 ± 5.188 (12)	71.792 ± 7.074 (12)	

TABLE 33

SMALL BONES, ASH DATA, TALUS

	Control Minus Deleted	Deleted Only	Immobilized	Exercise R	Exercise L	Reconditioned 5	Recon. 12	Range Test
Volume (mm^3)	2098.7 ±281.46 (27)	1870.0 ±117.1 (10)	1843.2 ±293.28 (32)	1889.9 ±223.6 (11)	1890.5 ±157.7 (11)	1866.1 ±282.13 (12)	2029.0 ±298.5 (20)	C-I**
Dry Weight (mg)	1986.6 ±224.89 (27)	1882.3 ±207.5 (10)	1487.0 ±226.47 (32)	1380.3 ±298.3 (11)	1438.6 ±276.6 (11)	1532.7 ±355.8 (12)	2102.4 ±303.0 (20)	C-I*** D-EL** C-ER*** D-R5** C-EL*** I-R12*** C-R5*** ER-R12*** D-I** EL-R12*** D-ER*** R5-R12***
Ash Weight (mg)	1181.2 ±151.14 (27)	1129.3 ±137.7 (10)	890.37 ±151.86 (32)	817.00 ±192.7 (11)	859.64 ±188.00 (11)	913.92 ±233.7 (12)	1293.1 ±186.7 (20)	C-I*** D-I** C-ER*** D-ER***I-R12*** C-EL*** D-EL**ER-R12*** C-R5*** D-R5**EL-R12*** C-R12* D-R12*R5-R12***
Density (mg/mm^3)	.96074 ±.15056 (27)	1.0080 ±.1198 (10)	.83219 ±.2104 (32)	.73364 ±.1586 (11)	.76455 ±.15397 (11)	.82833 ±.1777 (12)	1.0450 ±.1392 (20)	C-ER** ER-R12*** C-EL* EL-R12*** D-ER** R5-R12** D-EL* I-R12**
Ash Content (mg/mm^3)	.57000 ±.097112 (27)	.60400 ±.0845 (10)	.49875 ±.1325 (32)	.43364 ±.1071 (11)	.45818 ±.1104 (11)	.54250 ±.05659 (12)	.64400 ±.09918 (20)	C-I* D-EL* C-ER** I-R12*** C-EL* ER-R12*** D-I* EL-R12*** D-ER** R5-R12*
Per Cent Ash (%)	59.370 ±1.9279 (27)	59.970 ±3.368 (10)	59.762 ±2.709 (32)	59.018 ±2.876 (11)	59.573 ±2.925 (11)	59.300 ±2.832 (12)	61.500 ±1.6610 (20)	

TABLE 34

SMALL BONES, CHEMICAL DATA, TALUS

	Control Minus Deleted	Deleted Only	Immobilized	Exercise R	Exercise L	Reconditioned 5	Range Test
Ca Dry Wt. (mg/g)	238.00 ±28.62 (16)	230.20 ±16.90 (10)	229.13 ±33.65 (16)	223.00 ±12.73 (2)	210.33 ±20.32 (3)	209.71 ±13.66 (7)	
Ca Vol. (mg/cm^3)	238.81 ±35.27 (16)	232.60 ±35.44 (10)	204.00 ±45.73 (15)	157.00 ±33.94 (2)	173.00 ±25.00 (3)	166.86 ±51.60 (7)	
P Dry Wt. (mg/g)	103.00 ±8.173 (16)	103.30 ±6.993 (10)	102.53 ±6.022 (15)	98.500 ±7.778 (2)	96.667 ±13.50 (3)	102.29 ±6.576 (7)	
P Vol. (mg/cm^3)	104.31 ±21.34 (16)	104.20 ±13.38 (10)	85.200 ±19.15 (15)	69.500 ±16.26 (2)	83.333 ±18.90 (3)	81.571 ±26.60 (7)	
Mg Dry Wt. (mg/g)	2.8906 ±.2147 (16)	2.9420 ±.1983 (10)	2.9613 ±.3548 (16)	2.8300 ±.5233 (2)	2.5867 ±.3753 (3)	3.0843 ±.1563 (7)	
Mg Vol. (mg/cm^3)	2.9169 ±.4862 (16)	2.9610 ±.3349 (10)	2.7013 ±.8926 (15)	2.0150 ±.6859 (2)	2.1367 ±.4661 (3)	2.4171 ±.6471 (7)	
Ca/P	2.3169 ±.3143 (16)	2.2290 ±.1248 (10)	2.2771 ±.3132 (14)	2.4800 ±.2546 (2)	2.1133 ±.2363 (3)	2.0543 ±.1300 (7)	
Ca/Mg	82.550 ±9.843 (16)	78.350 ±4.028 (10)	78.313 ±15.48 (15)	86.050 ±1.485 (2)	81.800 ±5.880 (3)	68.200 ±6.454 (7)	

TABLE 35

SMALL BONES, ASH DATA, CALCANEUS

	Control Minus Deleted	Deleted Only	Immobilized	Exercise R	Exercise L	Reconditioned 5	Recon. 12	Range Test
Volume (mm^3)	3350.8 ±416.2 (28)	3192.5 ±279.9 (10)	2879.5 ±351.1 (32)	3232.3 ±291.5 (11)	3044.2 ±299.8 (11)	2988.3 ±530.0 (12)	3232.9 ±460.5 (20)	C-I*** I-R12*
Dry Weight (mg)	3073.3 ±311.5 (28)	3011.0 ±413.1 (10)	2263.0 ±428.8 (32)	2394.2 ±336.3 (11)	2229.1 ±395.0 (11)	2419.2 ±568.6 (12)	3296.7 ±397.6 (20)	C-I*** D-ER** EL- C-ER*** D-EL***R12*** C-EL*** D-R5** R5 - C-R5*** I-R12*** R12*** D-I*** ER-R12***
Ash Weight (mg)	1879.1 ±219.5 (28)	1841.8 ±293.2 (10)	1394.1 ±271.5 (32)	1427.9 ±226.0 (11)	1363.2 ±288.2 (11)	1483.5 ±373.3 (12)	2080.8 ±258.7 (20)	C-I*** D-ER** EL-R12*** C-ER*** D-EL***R5-R12*** C-EL*** D-R5** C-R5*** I-R12*** D-I*** ER-R12***
Density (mg/mm^3)	.92643 ±.1187 (28)	.94200 ±.0893 (10)	.80219 ±.1414 (32)	.74273 ±.1144 (11)	.74000 ±.1467 (11)	.81417 ±.1607 (12)	1.0305 ±.1368 (20)	C-I* D-ER** R5- C-ER** D-EL** R12*** C-EL** I-R12*** C-R12* ER-R12*** D-I* EL-R12***
Ash Content (mg/mm^3)	.56571 ±.07657 (28)	.57400 ±.0665 (10)	.48719 ±.09006 (32)	.44364 ±.07814 (11)	.45273 ±.1057 (11)	.50000 ±.1039 (12)	-.65150 ±.09016 (20)	C-I* D-ER*EL-R12*** C-ER* D-EL* R5-R12*** C-EL* D-R12* C-R12** I-R12*** D-I* ER-R12***
Per Cent Ash (%)	61.075 ±1.629 (28)	61.020 ±1.943 (10)	60.647 ±2.432 (32)	59.509 ±2.712 (11)	60.864 ±2.635 (11)	61.050 ±2.278 (12)	63.110 ±2.036 (20)	I-R12** ER-R12***

TABLE 36

SMALL BONES, CHEMICAL DATA, CALCANEUS

	Control Minus Deleted	Deleted Only	Immobilized	Exercise R	Exercise L	Reconditioned 5	Range Test
Ca Dry Wt. (mg/g)	230.52 ±37.89 (25)	237.10 ±25.20 (10)	220.10 ±25.41 (31)	213.88 ±12.12 (8)	212.10 ±18.08 (10)	211.83 ±13.84 (12)	
Ca Vol. (mg/cm^3)	220.80 ±49.60 (25)	223.70 ±40.14 (10)	174.87 ±30.59 (31)	167.88 ±26.83 (8)	158.80 ±39.05 (10)	173.25 ±36.31 (12)	C-I* C-ER* C-EL** C-R5* D-I* D-ER* D-EL** D-R5*
P Dry Wt. (mg/g)	107.57 ±13.95 (28)	104.50 ±5.523 (10)	105.53 ±18.50 (30)	97.000 ±4.626 (11)	100.73 ±3.197 (11)	105.42 ±7.609 (12)	
P Vol. (mg/cm^3)	101.36 ±20.96 (28)	98.500 ±12.10 (10)	83.400 ±16.54 (30)	72.545 ±13.37 (11)	75.545 ±17.711 (11)	86.583 ±20.34 (12)	C-I** C-ER*** C-EL*** C-R5* D-ER* D-EL*
Mg Dry Wt. (mg/g)	2.8964 ±.2037 (28)	2.9870 ±.1139 (10)	2.8913 ±.2401 (32)	2.8110 ±.2973 (10)	2.8536 ±.1669 (11)	3.0575 ±.3264 (12)	
Mg Vol. (mg/cm^3)	2.7168 ±.3919 (28)	2.8230 ±.2778 (10)	2.3084 ±.3984 (32)	2.2218 ±.4049 (11)	2.1009 ±.3978 (11)	2.4408 ±.4258 (12)	C-I** C-ER** C-EL*** D-I** D-ER** D-EL***
Ca/P	2.1296 ±.2710 (25)	2.2680 ±.2128 (10)	2.0734 ±.1961 (29)	2.1700 ±.13491 (7)	2.0790 ±.1546 (10)	2.0158 ±.1471 (12)	
Ca/Mg	80.252 ±14.34 (25)	79.380 ±7.816 (10)	76.116 ±9.520 (31)	74.157 ±5.176 (7)	74.270 ±6.911 (10)	70.667 ±7.190 (12)	

TABLE 37

SMALL BONES, ASH DATA, ULNA

	Control Minus Deleted	Deleted Only	Biopsy Pre Imm.	Immobilized	Exercised	Reconditioned 5	Range Test
Volume (mm^3)	782.93 ±324.1 (14)	879.50 ±261.8 (10)	284.13 ±98.64 (8)	894.75 ±378.5 (8)	868.63 ±349.0 (8)	1193.8 ±220.2 (4)	C-B** D-B** B-I** B-E** B-R***
Dry Weight (mg)	1299.9 ±611.5 (14)	1443.2 ±466.0 (10)	450.25 ±133.8 (8)	1326.4 ±514.0 (8)	1391.3 ±558.2 (8)	2125.3 ±173.8 (4)	C-B** C-R* D-B*** B-I** B-E** B-R***
Ash Weight (mg)	870.14 ±393.3 (14)	990.70 ±327.9 (10)	296.00 ±81.84 (8)	831.00 ±291.6 (8)	923.13 ±378.4 (8)	1451.0 ±105.6 (4)	C-B** C-R* D-B*** B-I** B-E** B-R***
Density (mg/mm^3)	1.6229 ±.0973 (14)	1.5830 ±.14190 (10)	1.6100 ±.1241 (8)	1.5050 ±.1054 (8)	1.5988 ±.1819 (8)	1.8050 ±.2017 (4)	I-R**
Ash Content (mg/mm^3)	1.0957 ±.0835 (14)	1.1180 ±.0476 (10)	1.0675 ±.1100 (8)	.96125 ±.1109 (8)	1.0575 ±.1387 (8)	1.2350 ±.1542 (4)	C-I* D-I* I-R**
Per Cent Ash (%)	66.736 ±4.146 (14)	68.520 ±1.163 (10)	66.212 ±3.130 (8)	63.712 ±3.540 (8)	66.025 ±1.723 (8)	68.350 ±.7594 (4)	D-I*

TABLE 38

SMALL BONES, CHEMICAL DATA, ULNA

	Control Minus Deleted	Deleted Only	Biopsy Pre Immob.	Immobilized	Exercise	Reconditioned 5	Range Test
Ca Dry Wt. (mg/g)	278.21 ±52.32 (14)	229.10 ±19.15 (10)	269.75 ±57.19 (8)	310.38 ±50.19 (8)	230.13 ±42.60 (8)	231.50 ±3.416 (4)	D-I** I-E** I-R*
Ca Vol. (mg/cm^3)	458.43 ±108.8 (14)	374.40 ±40.36 (10)	436.00 ±106.9 (8)	456.38 ±59.12 (8)	372.38 ±100.4 (8)	417.75 ±42.73 (4)	
P Dry Wt. (mg/g)	121.07 ±9.253 (14)	120.30 ±10.81 (10)	113.00 ±6.047 (8)	106.83 ±10.61 (6)	116.13 ±6.643 (8)	116.75 ±2.217 (4)	C-I* D-I*
P Vol. (mg/cm^3)	198.00 ±14.66 (14)	196.20 ±17.69 (10)	182.00 ±17.83 (8)	161.50 ±15.93 (6)	186.38 ±28.89 (8)	217.00 ±27.60 (4)	C-I** D-I** B-R* I-R**
Mg Dry Wt. (mg/g)	3.1771 ±.3812 (14)	3.1150 ±.2188 (10)	2.9933 ±.6000 (3)	2.8675 ±.3071 (8)	3.3838 ±.2837 (8)	3.3275 ±.1190 (4)	I-E*
Mg Vol. (mg/cm^3)	5.1943 ±.6152 (14)	5.0850 ±.4618 (10)	4.9333 ±.9500 (3)	4.3138 ±.6087 (8)	5.4350 ±.8678 (8)	6.0300 ±.8810 (4)	C-I* I-E* I-R**
Ca/P	2.3293 ±.5662 (14)	1.9120 ±.1759 (10)	2.4025 ±.5728 (8)	3.0533 ±.4721 (6)	1.9750 ±.3147 (8)	1.9800 ±.0115 (4)	C-I** D-I*** B-I** I-E*** I-R**
Ca/Mg	88.671 ±19.87 (14)	73.720 ±5.758 (10)	101.23 ±42.74 (3)	109.28 ±19.66 (8)	67.887 ±10.17 (8)	69.700 ±3.420 (4)	C-I* D-I** I-E*** I-R**

TABLE 39

SMALL BONES, ASH DATA, METATARSAL 1

	Control Minus Deleted	Deleted Only	Immobilized	Exercise R	Exercise L	Reconditioned 5	Range Test
Volume (mm^3)	804.88 ±95.15 (16)	789.20 ±91.60 (10)	818.83 ±102.8 (18)	421.00 ±355.0 (2)	664.67 ±68.19 (3)	540.00 ±271.9 (6)	C-ER** C-R** I-R** D-ER** D-R** I-ER**
Dry Wt. (mg)	891.25 ±107.8 (16)	904.30 ±91.49 (10)	843.23 ±106.7 (18)	616.50 ±290.6 (2)	776.67 ±110.1 (3)	614.83 ±312.8 (6)	C-R** D-R** I-R**
Ash Weight (mg)	561.00 ±62.77 (16)	584.90 ±75.15 (10)	531.67 ±71.33 (18)	388.50 ±197.3 (2)	526.67 ±55.15 (3)	378.33 ±201.0 (6)	C-R** D-R** I-R**
Density (mg/mm^3)	1.1106 ±.1034 (16)	1.1560 ±.1528 (10)	1.0400 ±.0884 (18)	1.8150 ±.8415 (2)	1.1667 ±.1115 (3)	1.1250 ±.1403 (6)	C-ER*** D-ER*** I-ER*** EL-ER*** R-ER***
Ash Content (mg/mm^3)	.69875 ±.0578 (16)	.75100 ±.1260 (10)	.65111 ±.0561 (18)	1.1250 ±.4738 (2)	.79000 ±.0100 (3)	.69000 ±.1238 (6)	C-ER*** D-ER*** I-ER*** EL-ER** R-ER***
Per Cent Ash (%)	63.087 ±1.166 (16)	64.530 ±2.814 (10)	62.989 ±1.651 (18)	62.400 ±2.546 (2)	68.133 ±7.729 (3)	61.367 ±5.239 (6)	EL-R*

TABLE 40

SMALL BONES, CHEMICAL DATA, METATARSAL 1

	Control Minus Deleted	Deleted Only	Immobilized	Exercise R	Exercise L	Reconditioned 5	Range Test
Ca Dry Wt. (mg/g)	238.69 ±40.84 (16)	228.50 ±15.58 (10)	248.22 ±39.47 (18)	273.50 ±.7071 (2)	249.67 ±45.00 (3)	210.17 ±6.242 (6)	
Ca Vol. (mg/cm^3)	265.00 ±50.83 (16)	265.60 ±46.84 (10)	255.06 ±32.19 (18)	497.50 ±231.2 (2)	289.00 ±37.32 (3)	236.50 ±33.79 (6)	C-ER*** D-ER*** I-ER*** ER-EL*** ER-R***
P Dry Wt. (mg/g)	104.81 ±7.054 (16)	109.90 ±6.983 (10)	105.94 ±6.188 (18)	110.00 ±1.414 (2)	115.67 ±13.01 (3)	110.33 ±9.585 (6)	
P Vol. (mg/cm^3)	116.53 ±13.30 (16)	127.70 ±21.75 (10)	109.50 ±10.50 (18)	194.50 ±84.15 (2)	134.33 ±5.033 (3)	123.83 ±19.52 (6)	C-ER*** D-ER*** I-ER*** ER-EL** ER-R***
Mg Dry Wt. (mg/g)	3.0194 ±.2624 (16)	2.9100 ±.1731 (10)	3.1711 ±.2641 (18)	3.5000 ±.2121 (2)	3.2733 ±.5481 (3)	3.2000 ±.4247 (6)	
Mg Vol. (mg/cm^3)	3.3650 ±.4889 (16)	3.2970 ±.5766 (10)	3.2811 ±.3887 (18)	6.4650 ±3.345 (2)	3.7933 ±.4676 (3)	3.5767 ±.4880 (6)	C-ER*** D-ER*** I-ER*** ER-EL*** ER-R***
Ca/P	2.2756 ±.4000 (16)	2.0920 ±.1839 (10)	2.3556 ±.4305 (18)	2.4850 ±.0354 (2)	2.1467 ±.1930 (3)	1.9150 ±.1480 (6)	
Ca/Mg	79.825 ±13.31 (16)	78.270 ±5.404 (10)	78.350 ±13.64 (18)	78.300 ±4.526 (2)	76.167 ±1.159 (3)	66.683 ±9.001 (6)	

TABLE 41

SMALL BONES, ASH DATA, METATARSAL 2

	MT 2 Control Minus Deleted	MT 2 Deleted Only	MT 2 Immobilized	Range Test
Volume (mm^3)	328.33 ±38.427 (6)	320.00 ±53.54 (4)	317.50 ±80.67 (6)	
Dry Wt. (mg)	542.67 ±56.60 (6)	535.75 ±67.09 (4)	528.83 ±130.75 (6)	
Ash Wt. (mg)	375.33 ±40.766 (6)	374.25 ±49.92 (4)	363.83 ±91.14 (6)	
Density (mg/mm^3)	1.6533 ±.0631 (6)	1.6825 ±.0866 (4)	1.6700 ±.05099 (6)	
Ash Content (mg/mm^3)	1.1450 ±.0550 (6)	1.1750 ±.0451 (4)	1.1467 ±.0372 (6)	
Per Cent Ash (%)	69.150 ±1.0654 (6)	69.825 ±1.001 (4)	68.733 ±1.659 (6)	

TABLE 42

SMALL BONES, CHEMICAL DATA, METATARSAL 2

	MT2 Control Minus Deleted	Deleted Only	MT2 Immobilized	Range Test
Ca Dry Wt. (mg/g)	248.17 ± 18.36 (6)	251.75 ± 28.41 (4)	277.33 ± 16.66 (6)	
Ca Volume (mg/cm^3)	410.00 ± 29.11 (6)	423.00 ± 44.33 (4)	462.33 ± 19.17 (6)	C-I*
P Dry Wt. (mg/g)	118.67 ± 7.815 (6)	117.00 ± 6.976 (4)	116.83 ± 5.565 (6)	
P Volume (mg/cm^3)	196.83 ± 19.53 (6)	196.50 ± 12.66 (4)	195.00 ± 7.950 (6)	
Mg Dry Wt. (mg/g)	3.0733 ± .2319 (6)	3.3675 ± .3303 (4)	3.0967 ± .3770 (6)	
Mg Volume (mg/cm^3)	5.0767 ± .3587 (6)	5.3975 ± .8963 (4)	5.1683 ± .6292 (6)	
Ca/P	2.0967 ± .1722 (6)	2.1600 ± .2968 (4)	2.3750 ± .1395 (6)	
Ca/Mg	80.983 ± 6.672 (6)	75.350 ± 11.01 (4)	90.533 ± 10.50 (6)	

TABLE 43

SMALL BONES, ASH DATA, METATARSAL 3

	MT 3 Control Minus Deleted	MT 3 Deleted Only	MT 3 Immobilized	Range Test
Volume (mm^3)	383.75 ±24.312 (8)	386.67 ±42.39 (6)	393.57 ±29.26 (7)	
Dry Weight (mg)	655.25 ±40.241 (8)	662.33 ±90.75 (6)	656.00 ±45.12 (7)	
Ash Weight (mg)	452.50 ±29.43 (8)	461.17 ±64.34 (6)	451.57 ±33.47 (7)	
Density (mg/mm^3)	1.7100 ±.06887 (8)	1.7100 ±.1222 (6)	1.6700 ±.05888 (7)	
Ash Content (mg/mm^3)	1.1813 ±.0610 (8)	1.1900 ±.0863 (6)	1.1486 ±.0524 (7)	
Per Cent Ash (%)	69.038 ±1.1275 (8)	69.617 ±.7414 (6)	68.829 ±1.465 (7)	

TABLE 44

SMALL BONES, CHEMICAL DATA, METATARSAL 3

	MT3 Control Minus Deleted	Deleted Only	MT3 Immobilized	Range Test
Ca Dry Wt. (mg/g)	238.75 ± 25.74 (8)	257.75 ± 21.38 (6)	248.86 ± 40.16 (7)	
Ca Volume (mg/cm^3)	408.25 ± 48.48 (8)	439.17 ± 34.44 (6)	416.43 ± 74.70 (7)	
P Dry Wt. (mg/g)	118.13 ± 6.244 (8)	111.00 ± 3.899 (6)	115.14 ± 7.105 (7)	
P Volume (mg/cm^3)	201.75 ± 17.85 (8)	190.00 ± 17.64 (6)	192.29 ± 13.14 (7)	
Mg Dry Wt. (mg/g)	2.9338 ± .1715 (8)	3.2083 ± .3000 (6)	3.0314 ± .2746 (7)	
Mg Volume (mg/cm^3)	5.0175 ± .3974 (8)	5.4733 ± .3773 (6)	5.0657 .5402 (7)	
Ca/P	2.0288 ± .2768 (8)	2.3250 ± .2676 (6)	2.1743 ± .4346 (7)	
Ca/Mg	81.825 ± 11.92 (8)	80.783 ± 10.68 (6)	81.829 ± 8.179 (7)	

TABLE 45

SMALL BONES, ASH DATA, METATARSAL 4

	MT 4 Control Minus Deleted	MT 4 Deleted Only	MT 4 Immobilized	Range Test
Volume (mm^3)	370.00 ±40.00 (6)	377.50 ±68.50 (8)	352.50 ±48.76 (6)	
Dry Weight (mg)	630.00 ±63.47 (6)	655.25 ±115.2 (8)	600.33 ±85.65 (6)	
Ash Weight (mg)	435.83 ±44.14 (6)	456.13 ±80.88 (8)	414.67 ±61.87 (6)	
Density (mg/mm^3)	1.6217 ±.2321 (6)	1.7363 ±.1186 (8)	1.7033 ±.0747 (6)	
Ash Content (mg/mm^3)	1.1817 ±.0788 (6)	1.2100 ±.0888 (8)	1.1750 ±.0532 (6)	
Per Cent Ash (%)	69.183 ±1.294 (6)	69.625 ±.7630 (8)	69.017 ±1.248 (6)	

TABLE 46

SMALL BONES, CHEMICAL DATA, METATARSAL 4

	MT4 Control Minus Deleted	Deleted Only	MT4 Immobilized	Range Test
Ca Dry Wt. (mg/g)	231.83 ± 25.65 (6)	254.63 ± 20.38 (8)	276.50 ± 34.15 (6)	C-I*
Ca Volume (mg/cm^3)	395.83 ± 51.43 (6)	443.50 ± 56.788 (8)	469.67 ± 42.64 (6)	
P Dry Wt. (mg/g)	118.00 ± 4.000 (6)	114.88 ± 6.490 (8)	118.50 ± 5.357 (6)	
P Volume (mg/cm^3)	201.33 ± 11.27 (6)	199.63 ± 14.64 (8)	201.83 ± 13.86 (6)	
Mg Dry Wt. (mg/g)	2.9317 ± .1720 (6)	3.2788 ± .3066 (8)	2.8700 ± .4238 (6)	
Mg Volume (mg/cm^3)	4.9983 ± .4066 (6)	5.7150 ± .7796 (8)	4.8783 ± .6581 (6)	
Ca/P	1.9617 ± .1876 (6)	2.2250 ± .2388 (8)	2.2683 ± .2255 (6)	
Ca/Mg	79.517 ± 12.47 (6)	78.112 ± 7.906 (8)	97.217 ± 12.16 (6)	C-I* D-I*

TABLE 47

WHOLE VERTEBRAL BODIES, ASH DATA, D12

	Complete Control	Control Minus Deleted	Deleted Only	Immobilized	Exercised	Reconditioned 5	Reconditioned 12	Range Test
Volume (mm^3)	2103.0 ± 592.12 (21)	2136.5 ± 602.95 (17)	1960.8 ± 604.2 (4)	2141.6 ±308.30 (16)	2103.7 ± 286.66 (11)	1924.3 ± 210.32 (6)	2228.2 ± 522.65 (9)	
Dry Weight (mg)	1297.9 ± 380.77 (21)	1308.4 ± 352.40 (17)	1253.3 ± 548.6 (4)	1234.7 ± 195.75 (16)	1188.5 ± 201.46 (11)	1143.8 ± 235.96 (6)	1495.8 ± 307.13 (9)	
Ash Weight (mg)	739.10 ± 237.94 (21)	741.94 ± 222.92 (17)	727.00 ± 334.9 (4)	720.38 ± 108.52 (16)	691.55 ±129.29 (11)	657.83 ± 122.74 (6)	877.56 ± 181.49 (9)	
Density (mg/mm^3)	.61619 ± .06376 (21)	.61471 ± .0605 (17)	.62250 ± .0866 (4)	.58125 ± .05536 (16)	.56455 ± .05203 (11)	.59500 ± .08849 (6)	.67778 ± .07710 (9)	E-R12•• I-R12••
Ash Content (mg/mm^3)	.35000 ± .04123 (21)	.34706 ± .0382 (17)	.36250 ± .0574 (4)	.33750 ± .03297 (16)	.32909 ± .03390 (11)	.34167 ± .04708 (6)	.39889 ± .05578 (9)	E-R12•• I-R12••
Per Cent Ash (%)	56.719 ± 3.3200 (21)	56.488 ± 3.606 (17)	57.700 ± 1.602 (4)	58.269 ± 2.7584 (16)	58.264 ± 2.157 (11)	57.683 ± 1.4176 (6)	58.656 ± 2.3823 (9)	

TABLE 48

WHOLE VERTEBRAL BODIES, ASH DATA, L2

	Complete Control	Control Minus Deleted	Deleted Only	Immobilized	Exercised	Reconditioned 5.	Reconditioned 12	Range Test
Volume (mm^3)	2891.3 ± 594.04 (23)	2845.1 ± 570.17 (19)	3110.5 ± 748.1 (4)	2856.2 ± 457.07 (16)	2994.1 ± 312.06 (11)	2703.2 ± 234.41 (6)	2986.5 ± 696.75 (10)	
Dry Weight (mg)	1752.3 ± 392.81 (23)	1715.6 ± 311.46 (19)	1926.3 ± 707.5 (4)	1680.8 ± 307.34 (16)	1734.5 ± 199.70 (11)	1610.0 ± 261.80 (6)	2015.8 ± 271.50 (10)	
Ash Weight (mg)	1004.9 ± 247.36 (23)	976.58 ± 199.50 (19)	1139.3 ± 425.2 (4)	976.75 ± 166.67 (16)	1005.3 ± 129.00 (11)	931.17 ± 141.35 (6)	1186.1 ± 198.74 (10)	
Density (mg/mm^3)	.60697 ± .06616 (23)	.60684 ± .0640 (19)	.60750 ± .0866 (4)	.59312 ± .06630 (16)	.58000 ± .05235 (11)	.59667 ± .08914 (6)	.69400 ± .10564 (10)	E-R12•• I-R12•
Ash Content (mg/mm^3)	.34696 ± .03994 (23)	.34526 ± .0382 (19)	.35500 ± .0532 (4)	.34563 ± .03723 (16)	.33727 ± .03608 (11)	.34500 ± .04680 (6)	.40700 ± .06325 (10)	E-R12••
Per Cent Ash (%)	57.170 ± 2.9295 (23)	56.789 ± 3.077 (19)	58.975 ± .9251 (4)	58.275 ± 2.0194 (16)	57.918 ± 2.2162 (11)	57.933 ± .65320 (6)	58.610 ± 2.5318 (10)	

TABLE 49

CORED VERTEBRAL BODIES, ASH DATA, D11

	Complete Control	Control Minus Deleted	Deleted Only	Immobilized	Exercised	Reconditioned 5	Reconditioned 12	Range Test
Volume (mm^3)	578.11 ± 220.46 (19)	578.93 ± 246.92 (15)	575.00 ± 84.16 (4)	496.46 ±164.91 (13)	578.86 ± 102.94 (7)	566.00 ± 230.79 (5)	552.00 ± 195.80 (10)	
Dry Weight (mg)	273.42 ± 86.835 (19)	277.07 ± 93.050 (15)	259.75 ± 67.23 (4)	227.46 ± 70.289 (13)	260.43 ± 50.451 (7)	206.00 ± 65.322 (5)	277.00 ± 84.768 (10)	
Ash Weight (mg)	155.47 ± 54.154 (19)	155.87 ± 58.389 (15)	154.00 ± 41.02 (4)	135.54 ± 42.043 (13)	155.43 ± 29.871 (7)	129.60 ± 27.546 (5)	160.20 ± 49.441 (10)	
Density (mg/mm^3)	.48526 ±.07486 (19)	.49467 ±.07539 (15)	.45000 ±.0707 (4)	.47231 ±.06760 (13)	.45000 ±.04435 (7)	.41800 ±.14043 (5)	.51400 ±.06275 (10)	
Ash Content (mg/mm^3)	.27263 ±.03798 (19)	.27467 ±.03852 (15)	.26500 ±.0404 (4)	.27538 ±.03099 (13)	.26857 ±.02968 (7)	.24800 ±.08319 (5)	.29600 ± .03921 (10)	
Per Cent Ash (%)	56.526 ± 3.7888 (19)	55.827 ± 3.9480 (15)	59.150 ± 1.330 (4)	59.569 ± 2.5388 (13)	59.729 ± 1.1996 (7)	59.560 ± 1.9424 (5)	57.830 ± 2.0385 (10)	

TABLE 50

CORED VERTEBRAL BODIES, ASH DATA, L1

	Complete Control	Control Minus Deleted	Deleted Only	Immobilized	Exercised	Recondition 5	Recondition 12	Range Test
Volume (mm^3)	720.67 ± 224.07 (24)	733.95 ± 222.47 (20)	654.25 ± 253.8 (4)	690.38 ± 159.62 (16)	798.73 ± 323.77 (11)	658.50 ± 214.57 (6)	873.80 ± 322.43 (10)	
Dry Weight (mg)	334.46 ± 81.092 (24)	345.30 ± 74.960 (20)	280.25 ± 100.6 (4)	329.13 ± 82.818 (16)	360.00 ± 133.15 (11)	292.50 ± 131.38 (6)	419.30 ± 125.03 (10)	
Ash Weight (mg)	192.58 ± 47.809 (24)	196.20 ± 45.225 (20)	174.50 ± 63.62 (4)	195.88 ± 43.888 (16)	215.55 ± 80.572 (11)	176.00 ± 75.044 (6)	242.40 ± 68.448 (10)	
Density (mg/mm^3)	.48542 ± .13458 (24)	.49600 ± .14222 (20)	.43250 ± .0793 (4)	.47688 ± .0688 (16)	.45455 ± .0468 (11)	.45000 ± .0984 (6)	.50200 ± .1113 (10)	
Ash Content (mg/mm^3)	.27875 ± .0682 (24)	.28000 ± .07277 (20)	.27250 ± .0457 (4)	.28500 ± .0331 (16)	.27273 ± .0338 (11)	.27000 ± .0544 (6)	.29400 ± .0672 (10)	
Per Cent Ash (%)	57.767 ± 4.059 (24)	56.870 ± 3.8202 (20)	62.250 ± 1.318 (4)	60.044 ± 3.107 (16)	59.900 ± 1.365 (11)	60,500 ± 1.339 (6)	58.110 ± 2.258 (10)	C/D-De

TABLE 51

CORED VERTEBRAL BODIES, ASH DATA, L7

	Complete Control	Control Minus Deleted	Deleted Only	Immobilized	Exercised	Reconditioned 5	Reconditioned 12	Range Test
Volume (mm^3)	988.64 ± 375.52 (22)	988.68 ± 394.85 (19)	988.33 ± 278.4 (3)	943.21 ± 262.92 (14)	1003.9 ± 354.19 (10)	1014.0 ± 235.11 (5)	1095.3 ± 270.83 (10)	
Dry Weight (mg)	482.86 ± 177.67 (22)	486.89 ± 184.75 (19)	457.33 ± 152.0 (3)	454.29 ± 120.59 (14)	448.6 ± 138.31 (10)	435.20 ± 48.757 (5)	566.20 ± 183.97 (10)	
Ash Weight (mg)	278.09 ± 99.856 (22)	277.58 ± 103.70 (19)	281.33 ± 88.82 (3)	276.93 ± 73.996 (14)	271.20 ± 87.064 (10)	263.60 ± 28.139 (5)	335.50 ± 108.87 (10)	
Density (mg/mm^3)	.50591 ± .14175 (22)	.51316 ± .15074 (19)	.46000 ± .0529 (3)	.48714 ± .0673 (14)	.45300 ± .0492 (10)	.44200 ± .0884 (5)	.50900 ± .0956 (10)	
Ash Content (mg/mm^3)	.29045 ± .0699 (22)	.29158 ± .07500 (19)	.28333 ± .0252 (3)	.29857 ± .0396 (14)	.27400 ± .0317 (10)	.26800 ± .0502 (5)	.30100 ± .0617 (10)	
Per Cent Ash (%)	58.032 ± 3.922 (22)	57.442 ± 3.8838 (19)	61.767 ± 1.234 (3)	60.964 ± 1.561 (14)	60.290 ± 1.3320 (10)	60.620 ± 1.5802 (5)	59.370 ± 1.765 (10)	

TABLE 52

WHOLE VERTEBRAL BODIES, CHEMICAL DATA, D12

	Complete Control	Control Minus Deleted	Deleted Only	Exercise	Range Test
Ca Dry Wt. (mg/g)	223.09 ± 17.07 (11)	220.14 ± 20.285 (7)	228.25 ± 9.639 (4)	223.27 ± 21.13 (11)	
Ca Volume (mg/cm^3)	137.55 ± 19.62 (11)	134.86 ± 19.68 (7)	142.25 ± 21.50 (4)	126.73 ± 20.90 (11)	
P Dry Wt. (mg/g)	102.09 ± 3.961 (11)	103.14 ± 3.934 (7)	100.25 ± 3.775 (4)	100.36 ± 4.675 (11)	
P Vol. (mg/cm^3)	63.091 ± 9.224 (11)	63.286 ± 8.995 (7)	62.750 ± 11.03 (4)	56.727 ± 5.022 (11)	
Mg Dry Wt. (mg/g)	3.3345 ± .1579 (11)	3.2957 ± .1859 (7)	3.4025 ± .0655 (4)	3.2545 ± .1773 (11)	
Mg Vol. (mg/cm^3)	2.0545 ± .2417 (11)	2.0171 ± .2371 (7)	2.1200 ± .2707 (4)	1.8382 ± .2037 (11)	
Ca/P	2.1882 ± .1783 (11)	2.1357 ± .1927 (7)	2.2800 ± .1186 (4)	2.2318 ± .2513 (11)	
Ca/Mg	66.909 ± 4.106 (11)	66.786 ± 4.694 (7)	67.125 ± 3.468 (4)	68.582 ± 5.067 (11)	

TABLE 53

WHOLE VERTEBRAL BODIES, CHEMICAL DATA, L2

	Complete Control	Control Minus Deleted	Deleted Only	Exercise	Range Test
Ca Dry Wt. (mg/g)	219.23 ± 19.69 (13)	214.78 ± 21.12 (9)	229.25 ± 12.97 (4)	228.00 ± 17.70 (11)	
Ca Vol. (mg/cm^3)	129.38 ± 23.13 (13)	125.22 ± 23.32 (9)	138.75 ± 22.82 (4)	133.00 ± 20.22 (11)	
P Dry Wt. (mg/g)	101.77 ± 5.495 (13)	100.33 ± 5.766 (9)	105.00 ± 3.464 (4)	99.727 ± 8.545 (11)	
P Vol. (mg/cm^3)	60.000 ± 9.310 (13)	58.333 ± 8.660 (9)	63.750 ± 10.94 (4)	58.000 ± 7.655 (11)	
Mg Dry Wt. (mg/g)	3.3385 ± .2056 (13)	3.3078 ± .2354 (9)	3.4075 ± .1103 (4)	3.2155 ± .1905 (11)	
Mg Vol. (mg/cm^3)	1.9608 ± .2792 (13)	1.9189 ± .3011 (9)	2.0550 ± .2301 (4)	1.8718 ± .2334 (11)	
Ca/P	2.1515 ± .1001 (13)	2.1367 ± .1030 (9)	2.1850 ± .0981 (4)	2.3027 ± .2675 (11)	
Ca/Mg	65.754 ± 5.606 (13)	65.056 ± 6.204 (9)	67.325 ± 4.277 (4)	70.991 ± 5.021 (11)	

TABLE 54

CORED VERTEBRAL BODIES, CHEMICAL DATA, D11

	Complete Control	Control Minus Deleted	Deleted Only	Immobilized	Exercise	Recondition 5	Range Test
Ca Dry Wt. (mg/g)	228.20 ± 43.422 (10)	241.83 ± 53.09 (6)	207.75 ± 5.377 (4)	217.85 ± 12.362 (13)	215.71 ± 6.102 (7)	217.60 ± 17.71 (5)	
Ca Vol. (mg/cm^3)	104.60 ± 27.204 (10)	112.50 ± 32.51 (6)	92.750 ± 12.09 (4)	101.38 ± 13.811 (13)	97.286 ± 10.86 (7)	90.200 ± 28.52 (5)	
P Dry Wt. (mg/g)	98.400 ± 9.766 (10)	97.000 ± 12.837 (6)	100.50 ± 1.291 (4)	103.08 ± 8.732 (13)	99.286 ± 4.348 (7)	99.800 ± 5.805 (5)	
P Vol. (mg/cm^3)	43.600 ± 5.060 (10)	42.667 ± 4.367 (6)	45.000 ± 6.377 (4)	47.923 ± 7.041 (13)	44.571 ± 5.028 (7)	41.600 ± 15.110 (5)	
Mg Dry Wt. (mg/g)	3.1300 ± .4153 (10)	3.0317 ± .5271 (6)	3.2775 ± .0780 (4)	3.2315 ± .2248 (13)	3.0600 ± .1882 (7)	3.3220 ± .3583 (5)	
Mg Vol. (mg/cm^3)	1.4160 ± .1814 (10)	1.3817 ± .1582 (6)	1.4675 ± .2262 (4)	1.5062 ± .2275 (13)	1.3814 ± .1685 (7)	1.3440 ± .3084 (5)	
Ca/P	2.3700 ± .5770 (10)	2.5417 ± .7098 (6)	2.1125 ± .1078 (4)	2.1215 ± .1332 (13)	2.1743 ± .0707 (7)	2.1820 ± .1370 (5)	
Ca/Mg	72.880 ± 20.26 (10)	79.200 ± 24.84 (6)	63.400 ± 1.896 (4)	67.715 ± 6.109 (13)	70.686 ± 3.868 (7)	66.060 ± 7.838 (5)	

TABLE 55

CORED VERTEBRAL BODIES, CHEMICAL DATA, L1

	Complete Control	Control Minus Deleted	Deleted Only	Immobilized	Exercise	Reconditioned 5	Range Test
Ca Dry Wt. (mg/g)	213.86 ± 15.816 (14)	208.60 ± 15.53 (10)	227.00 ± 6.164 (4)	226.38 ± 21.59 (16)	218.55 ± 13.18 (11)	217.33 ± 14.22 (6)	
Ca Vol. (mg/cm	101.07 ± 39.88 (14)	102.50 ± 46.91 (10)	97.500 ± 16.34 (4)	108.94 ± 24.55 (16)	99.727 ± 14.57 (11)	97.167 ± 17.53 (6)	
P Dry Wt. (mg/g)	100.86 ± 6.837 (14)	98.300 ± 4.990 (10)	107.25 ± 7.182 (4)	101.75 ± 6.923 (16)	99.636 ± 7.500 (11)	103.00 ± 7.899 (6)	
P Vol. (mg/cm	47.571 ± 16.52 (14)	48.100 ± 19.32 (10)	46.250 ± 7.719 (4)	48.438 ± 6.398 (16)	44.727 ± 7.604 (11)	46.000 ± 7.797 (6)	
Mg Dry Wt. (mg/g)	3.2686 ± .1848 (14)	3.2150 ± .1940 (10)	3.4025 ± .0386 (4)	3.2031 ± .1901 (16)	3.1564 ± .2590 (11)	3.3650 ± .2957 (6)	
Mg Vol. (mg/cm	1.5314 ± .5184 (14)	1.5560 ± .6004 (10)	1.4700 ± .2758 (4)	1.5294 ± .2270 (16)	1.4391 ± .1903 (11)	1.4867 ± .2287 (6)	
Ca/P	2.1214 ± .1334 (14)	2.1210 ± .1382 (10)	2.1225 ± .1408 (4)	2.1781 ± .4012 (16)	2.2018 ± .2045 (11)	2.1150 ± .1392 (6)	
Ca/Mg	65.521 ± 4.858 (14)	65.030 ± 5.602 (10)	66.750 ± 2.310 (4)	70.838 ± 7.080 (16)	69.773 ± 8.022 (11)	64.900 ± 5.796 (6)	

TABLE 56

CORED VERTEBRAL BODIES, CHEMICAL DATA, L7

	Complete Control	Control Minus Deleted	Deleted Only	Immobilized	Exercise	Reconditioned 5	Range Test
Ca Dry Wt. (mg/g)	224.58 ± 19.45 (12)	226.67 ± 21.81 (9)	218.33 ± 10.02 (3)	221.71 ± 12.58 (14)	215.45 ± 12.08 (11)	221.20 ± 8.438 (5)	
Ca Vol. (mg/cm^3)	108.42 ± 43.67 (12)	111.56 ± 50.65 (9)	99.000 ± 6.928 (3)	108.14 ± 15.71 (14)	98.000 ± 12.30 (11)	97.600 ± 17.05 (5)	
P Dry Wt. (mg/g)	101.92 ± 6.653 (12)	99.556 ± 5.961 (9)	109.00 ± 1.000 (3)	100.64 ± 6.134 (14)	100.91 ± 7.503 (11)	102.60 ± 6.465 (5)	
P Vol. (mg/cm^3)	48.667 ± 17.22 (12)	48.222 ± 19.992 (9)	50.000 ± 5.292 (3)	48.929 ± 7.011 (14)	45.818 ± 5.382 (11)	45.600 ± 9.555 (5)	
Mg Dry Wt. (mg/g)	3.1350 ± .3148 (12)	3.1667 ± .3619 (9)	3.0400 ± .0557 (3)	3.2136 ± .2081 (14)	3.1109 ± .1943 (11)	3.2380 ± .3784 (5)	
Mg Vol. (mg/cm^3)	1.4933 ± .5532 (12)	1.5256 ± .6383 (9)	1.3967 ± .1858 (3)	1.5643 ± .2206 (14)	1.4100 ± .1416 (11)	1.4180 ± .2002 (5)	
Ca/P	2.2208 ± .3176 (12)	2.2933 ± .3372 (9)	2.0033 ± .0723 (3)	2.2100 ± .1789 (14)	2.1391 ± .1405 (11)	2.1660 ± .1899 (5)	
Ca/Mg	73.083 ± 16.44 (12)	73.489 ± 19.13 (9)	71.867 ± 4.392 (3)	69.207 ± 5.728 (14)	69.391 ± 4.174 (11)	68.980 ± 7.725 (5)	

TABLE 57

PERIOSTEAL HISTOLOGY DATA, TIBIA

Histologic Index	CONTROL	IMMOBILIZED	EXERCISED	RECONDITIONED 5 MONTHS	RECONDITIONED 12 MONTHS	RANGE TEST
P (Perimeter, mm)	33.48 ±5.47 1.82 (9)	33.06 ±7.33 1.04 (5)	32.17 ±.941 .543 (3)	31.46 ±.734 .424 (3)	33.77 ±1.36 .481 (8)	
A_f (No. osteoid seams/mm)	.1713 ±.207 .073 (8)	.0350 ±.010 .005 (4)	.0567 ±.025 .014 (3)	.0833 ±.021 .012 (3)	.0788 ±.027 .010 (8)	
S_f (Circumference, osteoid seams; mm)	2.941 ±3.62 1.28 (8)	2.330 ±1.18 .59 (4)	1.600 ±1.57 .906 (3)	9.733 ±1.65 .953 (3)	9.828 ±5.59 1.98 (8)	C-R12** I-R12* ER-R12*
W.T. (Wall thickness; mm)	.1151 ±.059 .022 (7)	.1770 ±.011 .006 (2)	——	——	.1390 ±.017 .012 (2)	
M (Appositional rate; microns/day)	.9000 ±.272 .136 (4)	——	——	.9900 ±.137 .079 (3)	1.046 ±.235 .083 (8)	
M_f (Radial closure rate; mm/year)	.2275 ±.072 .036 (4)	——	——	.3167 ±.035 .020 (3)	.3713 ±.103 .036 (8)	
σ_f (Formation time; years)	.8950 ±.785 .555 (2)	——	——	——	——	
μ_f (Activation sites)	——	——	——	——	——	
% labeled system	26.57 ±19.5 7.37 (7)	——	——	65.33 ±20.4 11.8 (3)	68.75 ±29.5 10.4 (8)	C-R5* C-R12*
% No activity	63.67 ±33.8 11.3 (9)	74.00 ±21.2 9.48 (5)	64.67 ±32.5 18.8 (3)	16.00 ±3.46 2.00 (3)	31.50 ±31.2 11.0 (8)	
% Resorption	8.333 ±10.4 4.25 (6)	17.80 ±24.9 11.1 (5)	29.00 ±29.8 17.2 (3)	2.500 ±2.12 1.22 (2)	3.667 ±1.53 .883 (3)	
% Formation	34.63 ±30.1 10.6 (8)	10.50 ±7.05 3.53 (4)	6.333 ±3.51 2.03 (3)	82.33 ±2.52 1.45 (3)	67.13 ±30.3 10.7 (8)	C-R5* I-R12** C-R12* ER-R5** I-R5** ER-R12**
Bone formation rate surface based V_f; $mm^2/mm^2/year$	.1042 ±.065 .033 (4)	——	——	.2478 ±.008 .005 (3)	.2620 ±.152 .054 (8)	
M.C.T. (Mean cortical thickness)	1.716 ±.501 .167 (9)	1.188 ±.364 .163 (5)	1.045 ±.194 .112 (3)	1.409 ±.016 .009 (3)	1.910 ±.229 .081 (8)	C-I* ER-R12** C-ER* I-R12**
Bone formation rate volume based V_f; $mm^2/mm^2/year$	.0856 ±.075 .038 (4)	——	——	.1759 ±.007 .004 (3)	.1311 ±.068 .024 (8)	

TABLE 58

PERIOSTEAL HISTOLOGY DATA, FEMUR

Histologic Index	Control	Immobilized	Exercised Right	Exercised Left	Reconditioned 5	Reconditioned 12	Range Test
Perimeter :P, mm	43.62 ± 5.26 (21) 1.15	41.06 ± 3.82 (14) 1.02	44.20 ± .283 (2) .200	47.34 ± 4.37 (8) 1.55	43.08 ± 5.64 (6) 2.30	38.81 ± 5.38 (8) 1.90	I-EL* EL-R12*
BO.S./mm Mf	.3262 ±.153 (21) .033	.2490 ±.147 (14) .039	.3950 ±.049 (2) .035	.2738 ±.157 (8) .056	.1697 ±.086 (6) .035	.0715 ±.052 (8) .018	C-R12*** I-R12* ER-R12* EL-R12*
Circumf. O.S. Sf, mm	1.638 ±1.45 (21) .316	1.701 ±1.38 (14) .369	1.265 ±1.17 (2) .827	1.943 ±1.56 (8) .552	4.730 ±3.85 (6) 1.57	12.62 ±13.8 (8) 4.88	
Wall thickness W.T. mm	.0597 ±.011 (20) .002	.0579 ±.013 (14) .003	.0435 ±.002 (2) .001	.0594 ±.007 (8) .002	.0602 ±.011 (6) .004	.0589 ±.002 (8) .001	
Appositional Rate R, microns/day	.9584 ±.327 (19) .075	.4357 ±.364 (14) .097	1.375 ± .686 (2) .485	.6675 ±.431 (8) .152	1.088 ± .440 (6) .180	.8513 ±.344 (8) .122	C-I** I-ER* I-R5** I-R12*
Radial closure rate, mm Mf, yrs.	.3226 ±.138 (19) .032	.1244 ±.141 (14) .038	.4500 ±.325 (2) .230	.1850 ±.128 (8) .045	.3967 ±.159 (6) .065	.3088 ±.124 (8) .044	C-I** I-ER* I-R5** I-R12*
Formation time of yrs.	.2405 ±.159 (19) .036	1.406 ±1.36 (14) .363	.1300 ±.099 (2) .070	.6350 ±.593 (8) .210	.1850 ±.110 (6) .045	.2238 ±.106 (8) .037	
Activation sites, Mf	2.311 ±2.21 (19) .507	.5614 ±.708 (14) .189	4.075 ±2.72 (2) 1.92	.7088 ±.482 (8) .170	1.152 ± .638 (6) .260	.3513 ±.242 (8) .086	C-I** C-EL* C-R12* I-ER* ER-EL* ER-R5* ER-R12*
% Labelled system	24.10 ±13.4 (21) 2.92	22.29 ±19.7 (14) 5.27	19.00 ±12.73 (2) 9.00	18.50 ±14.77 (8) 5.22	48.17 ±30.62 (6) 12.5	55.38 ±38.5 (8) 13.6	EL-R12*
% No-activity	23.53 ±32.6 (20) 7.29	28.43 ±12.7 (14) 3.39	29.50 ±30.41 (2) 21.50	42.88 ±25.81 (8) 9.13	30.80 ±31.5 (5) 14.1	67.40 ±23.1 (5) 10.3	C-R12*
% Resorption	49.68 ±27.8 (20) 6.22	48.64 ±15.0 (14) 4.01	36.50 ± 3.54 (2) 2.50	27.38 ±17.55 (8) 6.20	23.50 ±17.98 (6) 7.34	2.750 ± .957 (4) .479	C-R12** I-R12**
% Formation	30.29 ±17.3 (21) 3.78	22.93 ±18.1 (14) 4.84	34.00 ±33.94 (2) 24.00	29.75 ±20.73 (8) 7.33	50.83 ±30.7 (6) 12.5	56.50 ±39.9 (8) 14.1	I-R12*
Bone formation rate surface based Vf, $mm^2/mm^2/yr.$	.1593 ±.104 (19) .024	.0459 ±.058 (14) .016	.1527 ±.064 (2) .045	.0919 ±.105 (8) .037	.3583 ±.320 (6) .131	.2047 ±.201 (8) .071	I-R5*** EL-R5*
M.C.T. Mean cortical thickness	1.508 ± .362 (21) .079	1.177 ± .209 (16) .052	1.120 ± .030 (2) .021	1.225 ± .394 (8) .139	1.235 ± .148 (7) .056	2.127 ± .336 (8) .119	C-R12*** I-R12*** ER-R12** EL-R12*** R5-R12***
Bone formation rate volume based Vf $mm^2/mm^2/yr.$	.1084 ±.064 (19) .015	.0425 ±.056 (14) .015	.1356 ±.053 (2) .037	.0712 ±.069 (8) .024	.2912 ±.256 (6) .105	.0902 ±.084 (8) .030	C-R5** I-R5*** EL-R5** R5-R12**

TABLE 59

PERIOSTEAL HISTOLOGY DATA, FIBULA

Histologic Index	CONTROL	IMMOBILIZED	EXERCISED RIGHT	EXERCISED LEFT	RECONDITIONED 4 MONTHS	RANGE TEST
P (Perimeter, mm)	15.03 ±.754 (10) .238	15.84 ±1.50 (8) .530	15.10 ±1.70 (2) 1.20	13.75 ±.495 (2) .350	15.28 ±1.00 (4) .50	
A_f (No. osteoid seams/mm)	.1950 ±.092 (10) .029	.1638 ±.105 (8) .037	.2000 ±.071 (2) .050	.2850 ±.247 (2) .175	.1450 ±.065 (4) .038	
S_f (Circumference, osteoid seams; mm)	3.987 ±4.18 (10) 1.32	1.439 ±.780 (8) .276	1.475 ±1.38 (2) .976	4.195 ±4.84 (2) 3.42	6.423 ±6.35 (4) 3.18	
W.T. (Wall thickness; mm)	.0738 ±.033 (10) .010	.0635 ±.012 (8) .004	——	.0455 ±.0007 (2) .0005	.0658 ±.001 (4) .001	
M (Appositional rate; microns/day)	.8011 ±.358 (9) .119	.2443 ±.111 (7) .042	.7750 ±.615 (2) .435	.5800 ±.410 (2) .290	1.235 ±.146 (4) .074	C-I** I-R4***
M_f (Radial closure rate; mm/year)	.2900 ±.138 (9) .046	.0557 ±.031 (7) .012	.2550 ±.262 (2) .185	.2100 ±.156 (2) .110	.4325 ±.050 (4) .025	C-I ** I-R4***
σ_f (Formation time; years)	.3756 ±.455 (9) .151	2.041 ±2.25 (7) .850	.4300 ±.438 (2) .310	.2800 ±.198 (2) .140	.1525 ±.017 (4) .009	
μ_f (Activation sites)	.8400 ±.527 (9) .176	.1571 ±.113 (7) .043	1.150 ±1.34 (2) .948	.9500 ±.212 (2) .150	.9300 ±.379 (4) .190	
% labeled system	56.89 ±29.2 (9) 9.73	15.29 ±14.2 (7) 5.37	35.50 ±41.7 (2) 29.5	57.50 ±47.4 (2) 33.5	68.75 ±31.8 (4) 15.9	I-R4*
% No activity	29.67 ±19.2 (9) 6.4	41.50 ±19.04 (8) 6.73	15.50 ±7.78 (2) 5.50	6.000 ±2.83 (2) 2.00	6.667 ±5.51 (3) 3.18	
% Resorption	25.14 ±20.7 (7) 7.82	36.29 ±19.3 (7) 7.29	48.00 ±32.5 (2) 23.0	56.00 ±1.41 (2) .997	35.00 ±25.4 (3) 12.7	
% Formation	55.70 ±28.0 (10) 8.85	26.75 ±17.9 (8) 6.33	36.5 ±40.3 (2) 28.5	63.00 ±39.6 (2) 28.0	68.75 ±31.8 (4) 15.9	
Bone formation rate surface based V_f; $mm^2/mm^2/year$	.1779 ±.131 (9) .044	.0145 ±.012 (7) .005	.137 ±.187 (2) .132	.1518 ±.165 (2) .117	.2949 ±.148 (4) .074	C-I* I-R4**
M.C.T. (Mean cortical thickness)	1.466 ±.345 (10) .109	1.137 ±.054 (8) .019	.9708 ±.128 (2) .091	1.122 ±.062 (2) .044	1.243 ±.117 (4) .059	
Bone formation rate volume based V_f; $mm^2/mm^2/year$	.1260 ±.097 (9) .032	.0127 ±.011 (7) .004	.1555 ±.213 (2) .151	.1314 ±.139 (2) .098	.2367 ±.112 (4) .056	I-R4**

TABLE 60

HAVERSIAN HISTOLOGY DATA, TIBIA

Histologic Index	CONTROL	IMMOBILIZED	EXERCISED	RECONDITIONED 5 MONTHS	RECONDITIONED 12 MONTHS	RANGE TEST
A_c (Cortical area/mm^2)	48.25 ±8.48 (10) 2.68	38.82 ±5.79 (8) 2.05	36.53 ±4.84 (3) 2.79	36.77 ±5.68 (4) 2.84	60.90 ±7.28 (4) 3.64	C-R12** R5-R12*** I-R12*** ER-R12**
C/T (Ratio cortical - total area)	.5860 ±.101 (10) .032	.4925 ±.054 (8) .019	.4400 ±.050 (3) .029	.4975 ±.026 (4) .013	.6525 ±.054 (4) .027	C-I* I-R12** C-ER* ER-R12* C-R5* R5-R12*
A_f (No. osteoid seams/mm^2)	1.508 ±1.04 (9) .347	1.256 ±.760 (5) .340	1.687 ±.867 (3) .501	.5100 ±.177 (3) .102	1.693 ±1.19 (4) .595	
A_r (No. resorption spaces/mm^2)	.2600 ±.269 (9) .090	.5960 ±.426 (5) .191	.7333 ±.484 (3) .279	.3767 ±.284 (3) .164	.4200 ±.188 (4) .094	
S_f (Circumference, osteoid seams)	.2633 ±.047 (9) .016	.2500 ±.066 (5) .030	.2367 ±.049 (3) .028	.2733 ±.103 (3) .059	.1775 ±.046 (4) .023	
M (Appositional rate, microns/day)	1.049 ±.261 (9) .087	.9600 ±.306 (5) .137	1.443 ±.578 (3) .334	1.333 ±.370 (3) .214	1.130 ±.330 (4) .165	
M_f (Radial closure rate; mm/year)	.2411 ±.090 (9) .030	.2080 ±.111 (5) .050	.4500 ±.190 (3) .110	.2833 ±.200 (3) .115	.2275 ±.128 (4) .064	
μ_f (Activation frequency foci/year)	6.056 ±5.13 (9) 1.71	4.060 ±4.16 (5) 1.86	10.07 ±8.30 (3) 4.79	2.513 ±2.40 (3) 1.39	7.375 ±7.46 (4) 3.73	
τ_f (Osteon formation time; years)	.3067 ±.115 (9) .038	.5140 ±.340 (5) .152	.2500 ±.150 (3) .087	.3167 ±.190 (3) .110	.3900 ±.271 (4) .136	
A_r/A_f (Ratio, resorption to formation)	.1667 ±.076 (9) .025	.4980 ±.196 (5) .088	.4033 ±.166 (3) .096	.6600 ±.452 (3) .261	.4925 ±.596 (4) .298	
V_f (Bone formation rate, mm^2/mm^2/year)	.1089 ±.095 (9) .032	.0765 ±.101 (5) .045	.1673 ±.143 (3) .083	.0500 ±.049 (3) .028	.1004 ±.115 (4) .058	
W.O.S. (Width, osteoid seams in microns)	8.300 ±1.99 (9) .663	7.620 ±3.47 (5) 1.55	9.733 ±.764 (3) .441	8.900 ±4.07 (3) 2.35	7.400 ±3.20 (4) 1.60	
% (Percent labeled system)	63.67 ±18.4 (9) 6.13	49.20 ±20.9 (5) 9.35	62.67 ±21.0 (3) 12.1	53.67 ±24.0 (3) 13.9	57.75 ±28.2 (4) 14.1	
W.T. (Wall thickness of completed osteon; mm)						

TABLE 61

HAVERSIAN HISTOLOGY DATA, FEMUR

Histologic Index	Control	Immobilized	Exercised Right	Exercised Left	Reconditioned 5	Reconditioned 12	Range Test
λ_c (Cortical area/mm^2)	62.11 ± 9.16 (21) 2.00	58.90 ±11.68 (16) 2.92	55.49 ± 9.85 (3) 5.69	67.95 ± 7.07 (8) 2.50	67.21 ±12.9 (7) 4.88	81.96 ± 9.54 (8) 3.37	C-R12*** EL-R12** I-R12*** R5-R12* ER-R12**
C/T (Ratio cortical-total area)	.4419 ±.072 (21) .016	.3950 ±.054 (16) .014	.3367 ±.012 (3) .007	.4000 ±.038 (8) .013	.3957 ±.038 (7) .014	.5450 ±.100 (8) .035	C-R12*** EL-R12*** I-R12*** R5-R12*** ER-R12***
λ_s (No. osteoid seams/mm^2)	2.482 ±1.49 (21) .325	1.434 ± .977 (16) .244	1.953 ±1.26 (3) .727	1.050 ± .297 (8) .105	.9029 ±.887 (7) .335	.2935 ±.510 (8) .180	C-I* C-R12*** C-EL* C-R5*
λ_r (No. resorption spaces/mm^2)	1.028 ± .837 (21) .183	.5219 ±.425 (16) .106	.7600 ±.318 (3) .184	.3938 ±.179 (8) .063	.4971 ±.583 (7) .220	.0851 ±.140 (7) 053	C-R12**
S_f (Circumference, osteoid seams)	.2229 ±.035 (21) .008	.2538 ±.043 (16) .011	.2667 ±.012 (3) .007	.2613 ±.045(8) .016	.2571 ±.014 (7) .005	.1850 ±.043 (8) .015	C-R12* EL-R12** I-R12*** R5-R12** ER-R12*
M Appositional rate, microns/day)	1.547 ±.349 (21) .076	1.627 ± .299 (16) .075	1.613 ± .388 (3) .224	1.506 ± .263 (8) .093	1.653 ±.298 (7) .113	1.099 ± .431 (8) .152	I-R12** R5-R12*
M_g (Radial closure rate, mm/yr)	.4891 ±.137 (21) .030	.4863 ±.116 (16) .029	.4500 ±.105 (3) .061	.3938 ±.157 (8) .056	.4843 ±.084 (7) .032	.3213 ±.192 (8) .068	
μ_f (Activation frequency foci/yr)	17.75 ±12.7 (21) 2.77	9.941 ±7.46 (16) 1.87	12.34 ± 8.20 (3) 4.73	5.404 ±1.89 (8) .668	6.413 ±6.95 (7) 2.63	1.877 ±3.71 (8) 1.31	C-I* C-R12** C-EL* C-R5*
σ_f (Osteon formation time, yrs)	.1667 ±.071 (21) .015	.1588 ±.039 (16) .010	.1667 ±.040 (3) .023	.2175 ±.098 (8) .035	.1543 ±.026 (7) .010	.3688 ±.328 (8) .116	I-R12** R5-R12*
λ_r/λ_s (Ratio, resorption to formation	.3543 ±.162 (21) .035	.4250 ±.254 (16) .064	.4233 ±.096 (3) .055	.3650 ±.102 (8) .036	.4400 ±.227 (7) .086	.3857 ±.364 (7) .138	
V_f (Bone formation rate), mm^2/mm^2/yr	.2842 ±.189 (21) .041	.1862 ±.135 (16) .034	.2382 ±.157 (3) .091	.1042 ±.045 (8) .016	.1180 ±.124(7) .047	.0309 ±.065 (8) .023	C-EL* C-R5* C-R12**
W.O.S. (Width, osteoid seams in microns)	9.029 ±1.50 (21) .328	8.663 ±1.66 (16) .415	11.57 ± 1.23 (3) .710	10.86 ± 1.40 (8) .495	9.729 ±1.81 (7) .684	6.363 ±1.97 (8) .697	C-R12*** ER-R12*** C-ER* EL-R12*** I-R12** R5-R12**
% (Per cent labelled system)	86.29 ±12.7 (21) 2.77	82.25 ±12.6 (16) 3.16	76.33 ± 1.15 (3) .664	70.50 ±22.86 (8) 8.08	81.57 ±11.9 (7) 4.50	75.75 ± 26.8 (8) 9.48	

TABLE 62

HAVERSIAN HISTOLOGY DATA, FIBULA

Histologic Index	CONTROL	IMMOBILIZED	EXERCISED RIGHT	EXERCISED LEFT	RECONDITIONED 4 MONTHS	RANGE TEST
A_c (Cortical area/mm^2)	15.47 ±2.65 (10) .838	13.70 ±2.84 (8) 1.00	12.20 ±2.83 (2) 2.00	12.45 ±1.06 (2) .750	14.53 ±2.33 (4) 1.17	
C/T (Ratio cortical - total area)	.8880 ±.059 (10) .019	.7813 ±.024 (8) .008	.7150 ±.035 (2) .025	.8350 ±.064 (2) .045	.8050 ±.065 (4) .033	C-I*** C-ER** C-R4*
A_f (No. osteoid seams/mm^2)	1.895 ±1.18 (10) .373	.9500 ±1.16 (8) .410	1.145 ±.672 (2) .475	1.965 ±1.55 (2) 1.10	1.615 ±.907 (4) .454	
A_r (No. resorption spaces/mm^2)	.4710 ±.397 (10) .126	.6650 ±.980 (4) .490	.2100 ±.156 (2) .110	1.185 ±.544 (2) .385	.6200 ±.754 (3) .435	
S_f (Circumference, osteoid seams)	.2130 ±.046 (10) .015	.1788 ±.064 (8) .023	.2250 ±.078 (2) .055	.3550 ±.007 (2) .005	.1775 ±.031 (4) .016	C-EL** EL-R** I-EL** EL-ER*
M (Appositional rate, microns/day)	1.143 ±.207 (10) .065	.6175 ±.584 (8) .206	1.640 ±.919 (2) .650	1.335 ±.021 (2) .015	.9675 ±.372 (4) .186	
M_f (Radial closure rate; mm/year)	.3810 ±.077 (10) .024	.1513 ±.177 (8) .063	.5450 ±.276 (2) .195	.4350 ±.049 (2) .035	.3475 ±.132 (4) .066	I-ER*
ν_f (Activation frequency foci/year)	12.38 ±10.3 (10) 3.26	4.564 ±9.75 (8) 3.45	7.770 ±.467 (2) .330	7.240 ±3.76 (2) 2.66	9.113 ±8.22 (4) 4.11	
σ_f (Osteon formation time; years)	.1790 ±.052 (10) .016	1.063 ±1.09 (8) .385	.1450 ±.078 (2) .055	.1750 ±.021 (2) .015	.2275 ±.085 (4) .043	
A_r/A_f (Ratio, resorption to formation)	.249 ±.088 (10) .028	.3875 ±.296 (4) .148	.2650 ±.290 (2) .205	.7150 ±.290 (2) .205	.2533 ±.240 (3) .139	
V_f (Bone formation rate, mm^2/mm^2/year)	.1748 ±.149 (10) .047	.0826 ±.190 (8) .067	.1176 ±.030 (2) .021	.3198 ±.280 (2) .198	.1228 .130 (4) .065	
W.O.S. (Width, osteoid seams in microns)	5.637 ±1.03 (10) .326	5.291 ±2.38 (8) .841	7.925 ±.530 (2) .375	8.775 ±.742 (2) .525	4.880 ±1.32 (4) .660	
% (Percent labeled system)	90.90 ±6.71 (10) 2.12	60.38 ±23.38 (8) 8.27	93.00 ±5.66 (2) 4.00	89.50 ±9.19 (2) 6.50	99.00 ±1.41 (4) .705	C-I*** I-R** I-ER* I-EL*
W.T. (Wall thickness of completed osteon; mm)						

TABLE 63

ENDOSTEAL HISTOLOGY DATA, TIBIA

Histologic Index	CONTROL	IMMOBILIZED	EXERCISED	RECONDITIONED 5 MONTHS	RECONDITIONED 12 MONTHS	RANGE TEST
P (Perimeter, mm)	22.49 ±3.93 (7) 1.49	22.82 ±2.55 (5) 1.14	24.17 ±.892 (3) .515	21.83 ±.860 (3) .497	21.43 ±4.76 (4) 2.38	
A_f (No. osteoid seams/mm)	.4329 ±.273 (7) .103	.1840 ±.070 (5) .031	.3100 ±.166 (3) .096	.2133 ±.029 (3) .017	.1833 ±.060 (3) .035	
S_f (Circumference, osteoid seams; mm)	2.003 ±2.76 (7) 1.04	2.354 ±.775 (5) .347	2.290 ±.815 (3) .471	4.380 ±1.64 (3) .947	3.813 ±1.34 (3) .774	
W.T. (Wall thickness; mm)	.1008 ±.050 (4) .025	.1850 ±.017 (4) .009	——	——	.1440 ±.027 (2) .019	C-I*
M (Appositional rate; microns/day)	1.070 ±.228 (6) .093	.9600 ±.354 (2) .250	1.295 ±.304 (2) .215	1.123 ±.176 (3) .102	.9167 ±.083 (3) .048	
M_f (Radial closure rate; mm/year)	.3650 ±.090 (6) .037	.2750 ±.092 (2) .065	.3950 ±.049 (2) .035	.4100 ±.066 (3) .038	.3200 ±.046 (3) .027	
σ_f (Formation time; years)	.3733 ±.250 (3) .144	.7650 ±.262 (2) .185	——	——	——	
μ_f (Activation sites)	1.600 ±1.40 (3) .808	.8000 ±.424 (2) .300	——	——	——	
% labeled system	52.71 ±34.8 (7) 13.2	12.50 ±5.69 (4) 2.85	36.67 ±20.1 (3) 11.6	87.33 ±10.4 (3) 6.00	60.50 ±39.6 (4) 19.8	I-R5*
% No activity	36.86 ±35.4 (7) 13.4	55.60 ±6.27 (5) 2.80	43.00 ±9.64 (3) 5.57	19.00 ±8.49 (2) 6.00	47.75 ±35.8 (4) 17.9	
% Resorption	12.20 ±14.1 (5) 6.31	6.000 ±6.16 (5) 2.75	1.500 ±.707 (2) .500	——	——	
% Formation	54.43 ±37.1 (7) 14.0	36.40 ±10.3 (5) 4.61	56.00 ±10.4 (3) 6.00	87.00 ±12.0 (3) 6.93	69.67 ±10.0 (3) 5.77	
Bone formation rate surface based V_f; $mm^2/mm^2/year$	.2390 ±.134 (6) .055	.1475 ±.095 (2) .067	.2355 ±.011 (2) .008	.3783 ±.143 (3) .083	.2065 ±.027 (3) .016	
M.C.T. (Mean cortical thickness)	1.750 ±.561 (7) .212	1.188 ±.364 (5) .163	1.045 ±.194 (3) .112	1.409 ±.016 (3) .009	2.011 ±.288 (4) .144	I-R12* ER-R12*
Bone formation rate volume based V_f; $mm^2/mm^2/year$	.1796 ±.170 (6) .069	.1316 ±.107 (2) .076	.2050 ±.023 (2) .016	.2699 ±.104 (3) .060	.1016 ±.024 (3) .014	

TABLE 64

ENDOSTEAL HISTOLOGY DATA, FEMUR

Histologic Index	Control	Immobilized	Exercised Right	Exercised Left	Reconditioned 5	Reconditioned 12	Range Test
Perimeter P, mm	33.379 ± 6.11 (21) 1.33	33.16 ± 5.31 (14) 1.42	38.10 ± 4.38 (2) 3.10	39.04 ± 4.66 (9) 1.55	38.05 ± 8.26 (6) 3.37	26.76 ± 3.96 (8) 1.40	EL-R12***
BO.S./mm A_f	.6855 ±.298 (20) .067	.4256 ±.207 (14) .055	.7100 ±.283 (2) .200	.3711 ±.276 (9) .092	.6350 ±.235 (6) .096	.2071 ±.095 (7) .036	
Circumf. O.S. S_f, mm	1.933 ±1.12 (20) .250	1.146 ± .507 (14) .136	1.165 ± .049 (2) .035	.8767 ±.450 (9) .150	2.002 ±1.51 (6) .617	2.321 ±1.40 (7) .529	
Wall thickness W.T. mm	.0702 ±.013 (19) .003	.0698 ±.009 (14) .002	.0680 ±.010 (2) .007	.0759 ±.004 (9) .001	.0712 ±.011 (6) .004	.0615 ±.021 (8) .007	
Appositional Rate ll, microns/day	1.485 ± .242 (20) .054	.8021 ±.472 (14) .126	1.170 ± .014 (2) .010	.9111 ±.457 (9) .152	1.248 ±.300 (6) .122	.6557 ±.204 (7) .077	C-I*** C-EL*** C-R12*** R5-R12*
Radial closure rate, mm E_f, yrs.	.5305 ±.102 (20) .023	.2843 ±.179 (14) .048	.4250 ±.007 (2) .005	.3033 ±.178 (9) .059	.4550 ±.111 (6) .045	.2386 ±.073 (7) .028	C-I*** C-EL*** C-R12*** R5-R12*
Formation time of yrs.	.1367 ±.039 (18) .009	.4621 ±.532 (14) .142	.1550 ±.021 (2) .015	.4333 ±.401 (9) .134	.1625 ±.049 (6) .020	.4014 ±.208 (7) .079	
Activation sites, A_f	5.639 ±2.76 (18) .651	2.089 ±2.22 (14) .593	4.750 ±2.47 (2) 1.75	1.600 ±1.69 (9) .563	4.535 ±3.11 (6) 1.27	.5543 ±.270 (7) .102	C-I** C-EL*** C-R12***
% labelled system	80.75 ±21.7 (20) 4.85	28.71 ±23.1 (14) 6.17	54.50 ± 23.3 (2) 16.5	20.22 ±20.55 (9) 6.85	77.17 ±24.4 (6) 9.96	49.43 ±26.1 (7) 9.86	C-I*** C-EL*** C-R12* I-R5*** EL-R5***
% No-activity	17.64 ±24.8 (21) 5.41	47.57 ±24.9 (14) 6.65	35.00 ±25.5 (2) 18.0	65.56 ±19.49 (9) 6.50	17.20 ±20.5 (6) 8.37	52.63 ±30.7 (8) 10.9	C-EL*** EL-R5**
% Resorption	6.406 ±7.26 (18) 1.71	15.50 ± 8.62 (14) 2.30	10.00 ± 2.83 (2) 2.00	10.44 ± 5.48 (9) 1.83	5.633 ±4.54 (6) 1.85	8.000 ±9.20 (4) 4.60	
% Formation	80.70 ±20.4 (20) 4.56	36.93 ±25.7 (14) 6.87	55.00 ±22.6 (2) 16.0	24.00 ±21.6 (9) 7.2	77.17 ±24.4 (6) 9.96	49.57 ± 25.9 (7) 9.79	C-I*** C-EL*** C-R12* I-R5** EL-R5***
Bone formation rate surface based V_f, $mm^2/mm^2/yr$.	.6497 ±.268 (20) .060	.1704 ±.208 (14) .056	.3532 ±.149 (2) .105	.1213 ±.147 (9) .049	.5284 ±.299 (6) .122	.1061 ±.065 (7) .025	C-I*** C-EL*** C-R12*** I-R5 ** EL-R5 ** R5-R12 *
M.C.T. Mean cortical thickness	1.480 ± .331 (21) .072	1.177 ± .209 (16) .052	1.120 ± .030(2) .021	1.195 ± .379 (9) .126	1.235 ±.148 (7) .056	2.126 ± .336 (8) .119	C-R12*** I-R12 *** ER-R12*** EL-R12*** R5-R12***
Bone formation rate volume based V_f $mm^2/mm^2/yr$.	.4853 ±.271 (20) .061	.1461 ±.175 (14) .047	.3138 ±.125 (2) .088	.1182 ±.164 (9) .055	.4379 ±.244 (6) .100	.0518 ±.030 (7) .011	C-I** C-EL*** C-12*** I-R5* R5-R12* EL-R5*

TABLE 65

ENDOSTEAL HISTOLOGY DATA, FIBULA

Histologic Index	CONTROL	IMMOBILIZED	EXERCISED RIGHT	EXERCISED LEFT	RECONDITIONED 4 MONTHS	RANGE TEST
P (Perimeter, mm)	4.818 ±1.41 (10) .446	7.994 ±.773 (8) .273	7.865 ±.387 (2) .415	5.675 ±1.61 (2) 1.14	6.975 ±1.90 (4) .950	C-I*** C-ER* C-R*
^{n}f (No. osteoid seams/mm)	.4980 ±.269 (10) .085	.3025 ±.174 (8) .062	.2850 ±.021 (2) .015	.3100 ±.028 (2) .020	.3825 ±.179 (4) .090	
S_f (Circumference, osteoid seams; mm)	1.759 ±1.93 (10) .610	2.135 ±1.83 (8) .647	2.780 ±.523 (2) .370	.8700 ±.354 (2) .250	2.223 ±1.03 (4) .515	
W.T. (Wall thickness; mm)	.0789 ±.013 (10) .004	.0837 ±.012 (7) .004	.0670 ±.013 (2) .009	.0790 ±.006 (2) .004	.1053 ±.013 (4) .007	ER-R*
M (Appositional rate; microns/day)	.878 ±.321 (10) .102	.6550 ±.293 (8) .104	2.030 ±.382 (2) .270	1.260 ±.198 (2) .140	1.563 ±.470 (4) .235	C-ER** I-R** C-R** I-ER***
M_f (Radial closure rate; mm/year)	.317 ±.118 (10) .037	.2263 ±.119 (8) .042	.7400 ±.141 (2) .100	.4600 ±.071 (2) .050	.5700 ±.173 (4) .087	C-ER** I-R** C-R** I-ER***
^{a}f (Formation time; years)	.285 ±.121 (10) .038	.6671 ±.727 (7) .275	.0950 ±.035 (2) .025	.1750 ±.035 (2) .025	.1925 ±.054 (4) .027	
$^{\mu}f$ (Activation sites)	1.894 ±1.02 (10) .323	.9314 ±.822 (7) .311	3.170 ±.948 (2) .670	1.825 ±.530 (2) .375	1.913 ±.361 (4) .181	I-ER*
% labeled system	58.70 ±34.4 (10) 10.9	31.75 ±24.3 (8) 8.59	79.00 ±19.80 (2) 14.0	25.50 ±10.6 (2) 7.50	72.50 ±11.2 (4) 5.60	
% No activity	34.44 ±31.25 (9) 10.4	47.00 ±31.5 (7) 11.9	21.00 ±19.80 (2) 14.0	32.50 ±36.1 (2) 25.5	17.75 ±8.77 (4) 4.38	
% Resorption	10.67 ±7.05 (9) 2.35	7.333 ±5.51 (3) 3.18	—.—	42.00 ±46.7 (2) 33.0	9.750 ±10.8 (4) 5.4	
% Formation	59.40 ±33.80 (10) 10.69	56.13 ±35.6 (8) 12.6	79.00 ±19.80 (2) 14.00	25.50 ±10.6 (2) 7.50	72.50 ±11.2 (4) 5.60	
Bone formation rate surface based V_f; $mm^2/mm^2/year$	.2164 ±.164 (10) .052	.0925 ±.078 (8) .028	.5757 ±.041 (2) .029	.1188 ±.020 (2) .014	.425R ±.195 (4) .098	C-ER** I-R** C-R* ER-EL* I-ER** EL-R*
M.C.T. (Mean cortical thickness)	1.466 ±.345 (10) .109	1.137 ±.054 (8) .019	.9708 ±.128 (2) .091	1.122 ±.062 (2) .044	1.243 ±.117 (4) .059	
Bone formation rate volume based V_f; $mm^2/mm^2/year$	.1760 ±.144 (10) .046	.0815 ±.070 (8) .025	.5954 ±.036 (2) .025	.1065 ±.024 (2) .017	.3368 ±.134 (4) .067	C-ER*** I-ER*** ER-R* I-R** ER-EL**

B. The reformatted data for an entire group were then pooled. A summary curve was then calculated by BMDO2R. This curve was "forced" to a cubic passing through the origin.

C. Plots were generated by the program "PLTSRC" and and off-line plotter at Wright-Patterson Air Force Base, Dayton, Ohio. The first plot consisted of all the data and individual curves for the entire group (see Figures 2 and 3 in the main report). The remaining plots were generally of summary curves and the CONTROL summary curve (see Figure 5 in the main report).

D. The program "CUBEFIT" was developed specifically for this study. It generated an F-statistic for the two groups in question using the mean, standard deviation, and degrees of freedom for each group.

E. To complete this analysis, a summary table was compiled. This table included the following values:

N - number of data points in group
r - correlation coefficient (from BMDO2R)
σ - standard deviation (from BMDO2R)
F - F-statistic (from CUBEFIT)

II. Compliance Analysis (Load Analysis)

A. A program (LOAD) was developed to interpolate the extension of the ligament at predetermined loads from the slope data. The slope data consisted of loads at extensions of 5, 10, 15, 25, 35, 45, 55, 65, 70, and 75 mm.

After various runs of LOAD at different loads, it was determined the extension in the "toe region" (i.e., extensions of 5, 10, and 15 mm) was the most significant area of the curve for this study. We compared the sham-treated ligaments with the steroid-treated ligaments at loads of 5, 10, 15, 20, 25, and 30 kg.

The sham and steroid slope data for a group were input into LOAD. A difference in the extension of the sham and steroid ligaments for a particular monkey was computed in two ways. The first was a simple subtraction of the two values. The second was a percent change calculated by the formula $\frac{A-B}{(A+B)/2}$, where A was sham and B was steroid.

B. Means and standard deviations for both values at each load were reported. A t-test for the group was performed. All of the results were printed on the computer tab.

III. Linear Analysis

A. The toe region of each ligament's slope data was dropped for this study; i.e., the loads at extensions of 5, 10, and 15 mm were not included.

B. The remaining data points for each ligament were used to calculate linear equations according to the following procedures:

(1) If either the sham-treated or the steroid-treated ligament of a monkey had only one remaining data point, the data from both ligaments were excluded from the study, since a linear equation could not be calculated from the one data point, and a comparison could not be made without an equation for each ligament.

(2) If exactly two data points remained for a ligament, the linear equation was hand-calculated using the equations:

$$m = \frac{y_2 - y_1}{x_2 - x_1}, \text{ where y=load and x=extension}$$

$$b = \frac{y_1}{x_1(m)}$$

$$y = mx + b$$

(3) Linear equations were calculated for ligaments with three or more remaining data points using the BMDO2R linear regression program.

C. The linear equations were submitted to the program DIF, which generated a slope and intercept for each monkey.

IV. Strength Analysis

A. The program MEANDIF was run on the output from DIF (see Appendix E, IIIC). Means and standard deviations for each variable, each group, and each side were computed (e.g., maximum load, group 4, sham side).

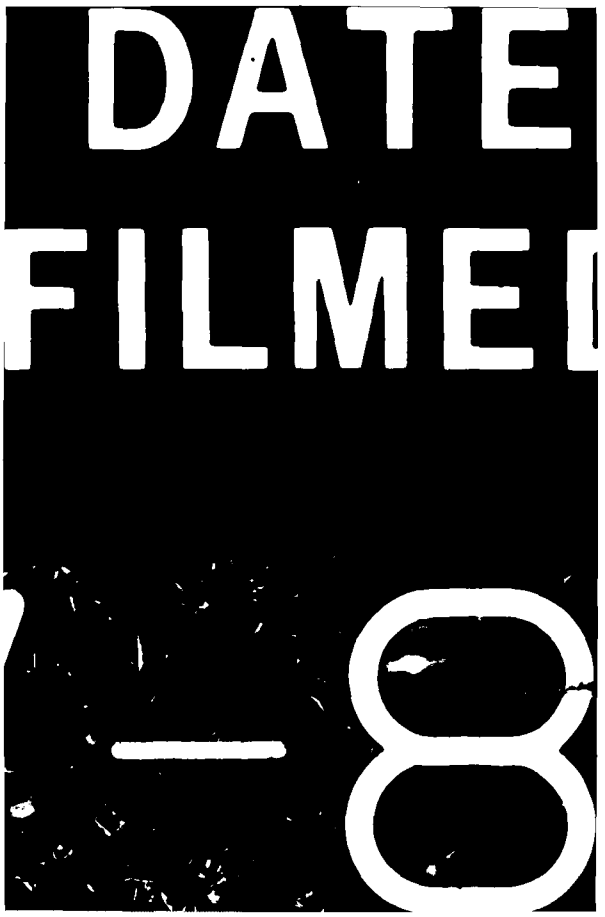
B. Percent differences were calculated.

C. A paired comparison t-test was performed by MEANDIF to compare the difference between the sham-treated ligaments and the steroid-treated ligaments for each variable.

D. The Analysis of Variance Series (see Appendix B) was run on the data.

E. Tables of the means and standard deviations, paired comparison t-test values, etc. were made.

*U.S.Government Printing Office: 1983 — 659/005/2047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